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ACTIVE MATRIX LIQUID CRYSTAL DISPLAY

INDUSTRY SURVEY RESULTS

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A SURVEY EXPLORING SUCH ASPECTS OF AMLDC AS RESOLUTION, FIXED CONFIGURATION, VIEWING ANGLE, CONTRAST, LUMINANCE, GREY SHADES, CHROMATICITY, ETC., WAS DISTRIBUTED TO POTENTIAL DOMESTIC PRODUCERS AND COMPONENT MANUFACTURERS OF AMLCD'S. THIS REPORT SUMMARIZES THE RESPONSES RECEIVED FROM THE POLLED COMPANIES. THE PURPOSE OF THE SURVEY WAS TO DETERMINE CURRENT AND NEAR-FUTURE STATE-OF-THE-ART AMLCD TECHNOLOGY IN THE UNITED STATES.

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ACTIVE MATRIX LIQUID CRYSTAL DISPLAYS

INDUSTRY RESULTS

1.0 INTRODUCTION

To support the creation of a standard for Active Matrix Liquid Crystal Displays (AMLCDs), ARINC Research Corporation was tasked by Wright Laboratories Cockpit Avionics Office (WL) to question various industry experts on AMLCDs. On September 30, 1993 a survey exploring such aspects of AMLCDs as resolution, pixel configuration, viewing angle, contrast, luminance, gray shades, chromaticity, etc., was distributed to potential domestic producers and component manufacturers of AMLCDs. This report summarizes the responses ARINC received from the polled companies.

2.0 PURPOSE

The purpose of the survey was to determine current and near future state-of-the-art of AMLCD technology in the United States. A total of 89 questions were asked on various aspects of AMLCDs. The results of the survey will assist WL in establishing an AMLCD standard for government and possibly commercial applications. The survey was separated into ten areas: resolution, pixel configuration, viewing angle, contrast, gray shades, luminance, chromaticity, NVIS compatibility, time based effects, and display effects. In each section, the questions were formatted where applicable to determine:

1. What is state-of-the-art?
2. What is perceivable with the human eye?
3. Can these goals currently be obtained; if not, when?
4. What are the cost and reliability relationships?
5. What would you recommend?

Respondents were encouraged to provide additional information to the multiple choice and fill-in-the-blank questionnaire format.

3.0 SURVEY PARTICIPANTS

The companies polled were identified as either potential producers of AMLCDs or as a vendor of major subassemblies or components used to construct AMLCDs. Of the 59 surveys distributed on September 30, 1993, 18 responses were received. A survey distribution and response list is provided in Appendix A. The companies were notified by ARINC to explain the purpose of the survey and to identify an appropriate point of contact within each company. Responses were requested by October 15, 1993, but were accepted until November 15, 1993.

4.0 SURVEY RESULTS

Table 4-1 presents cumulative results obtained from the returned surveys. The first column lists the question number and multiple choice or fill-in-the-blank answer to the questions which can be found in Appendix B. The second column lists the number of responses received for each of the answers from the first column. The third column presents the percentage of responses given for an answer. The final column contains the cumulative percentage of responses with 100% given to the most inclusive capability. Most multiple choice answers include the selection *other* where respondents could provide additional information or a different answer. General comments were also encouraged. *Other* answers and general comments received can be found immediately following the answer columns of each question. The number of answers received for each question along with *other* answers have been added to the survey in Appendix B.

Table 4-1. AMLCD Industry Survey Results

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
1. What is the maximum resolution state-of-the-art color Active Matrix Liquid Crystal Display (AMLCD) technology has achieved?			
a. 80 pixels/inch	4	25.0	100.0
b. 100 pixels/inch	1	6.3	75.0
c. 120 pixels/inch	6	37.5	68.8
d. 140 pixels/inch	3	18.8	31.3
e. Other	2	12.5	12.5
e. 169 color groups/inch direct view 180 pixels per inch			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · 300 laboratory · 775 LPI (small area light values 35 μm pixels · 125 development · 128 triad 4x4 · 1280x1024 near production			
2. What is the maximum resolution state-of-the-art monochrome AMLCD technology has achieved?			
a. 80 pixels/inch	1	6.7	100.0
b. 100 pixels/inch	1	6.7	93.3
c. 120 pixels/inch	0	0	86.7
d. 140 pixels/inc	1	6.7	86.7
e. Other	12	80.0	80.0
e. 145, 160 (80 quad), 164, 200, > 210, 230, 256, 280, 284, 300, 500, 508			
General Comments: · 250 development			
3. For the display data listed below, what value of resolution do you feel will allow the display to provide performance at the limits of human perception (pixels/inch)?			
a. Alphanumeric			
50	2	12.5	12.5
76	1	6.3	18.8
80	3	18.8	37.5
<100	1	6.3	43.8
100	3	18.8	62.5
120	1	6.3	68.8
125	1	6.3	75.0
150	1	6.3	81.3
169	1	6.3	87.5
200	1	6.3	93.8
300	1	6.3	100.0

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
b. Graphic Data			
80	1	6.3	6.3
100	6	37.5	43.8
120	1	6.3	50.0
125	1	6.3	56.3
150	2	12.5	68.8
169	1	6.3	75.0
200	2	12.5	87.5
250	1	6.3	93.8
300	1	6.3	100.0
c. Color Video			
82	1	5.9	5.9
100	3	17.7	23.5
120	2	11.8	35.3
125	1	5.9	41.2
128	1	5.9	47.1
140	1	5.9	52.9
150	2	11.8	64.7
169	1	5.9	70.6
200	2	11.8	82.4
250	1	5.9	88.2
300	2	11.8	100.0
d. Mono Video			
100	2	12.5	12.5
120	1	6.3	18.8
128	1	6.3	25.0
140	2	12.5	37.5
150	2	12.5	50.0
160 min	1	6.3	56.3
164	1	6.3	62.5
200	1	6.3	68.8
250	2	12.5	81.3
300	2	12.5	93.8
318	1	6.3	100.0

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · Depends on video content · Depends on viewing distance · Viewing distant dependent · Not possible to answer, varies widely and impeded by many things			
4. If current resolution capabilities are not capable of providing adequate visual performance, when do you believe the resolution capability will meet or exceed the requirement?			
current	5	38.5	38.5
a. 1 year	0	0	38.5
b. 2 years	1	7.7	46.2
c. 3 years	3	23.1	69.2
d. 4 years	4	30.8	100.0
e. > 5 years	0	0	100.0
General Comments: · High resolution causes reduction in aperture ratio and loss of an already limited transmission. For displays that need to be sunlight readable, I don't see these resolutions becoming valuable. Also, they may not be necessary considering cockpit viewing distances. Note that bandwidth of video systems will need to significantly improve. · Current capability adequate · Available now · We are buying now for simulator use: VGA. We are targeting 768x1028 for December 1996 technology availability date for use on aircraft.			
5. What function best describes the cost versus resolution curve for AMLCD? (Sketch if possible)			
a. Linear	1	7.7	N.A.
b. Square Law	4	30.8	
c. Exponential	7	53.9	
d. Other	1	7.7	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

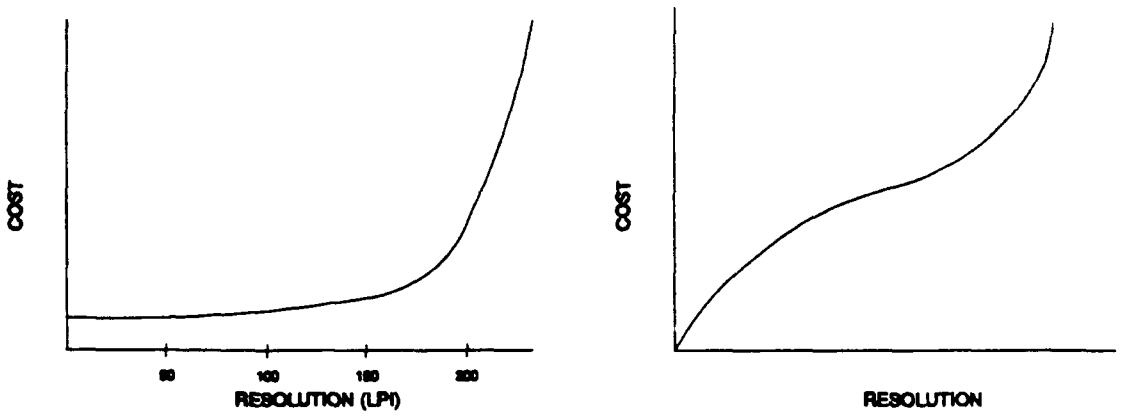
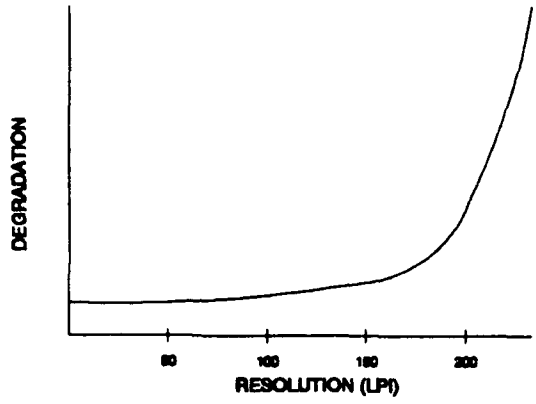
Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
d. 			
General Comments: · Cost is more directly related to total pixel count which requires more LCD drivers. · Don't have data. · Don't know. · At least a square law. 80 per inch today is not much more costly than 60 per inch, but 120 per inch isn't available at any cost in large displays. · Limited need (market) for > 150/inch displays will make a premium for price.			
6. What function best describes the reliability degradation versus resolution curve for AMLCDs? (Sketch if possible)			
a. Linear	4	28.6	N.A.
b. Square Law	5	35.7	
c. Exponential	5	35.7	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
c. Square root (2) Square law (2) None/Other			



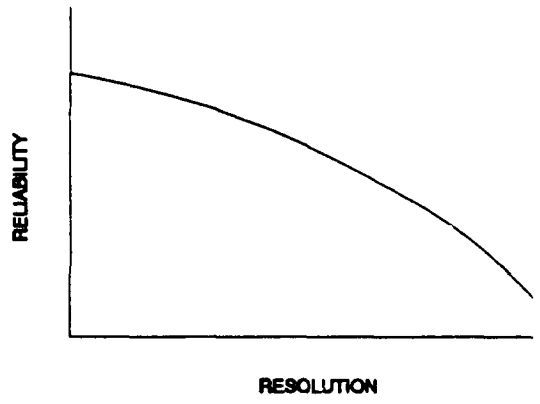


Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · There should be no degradation. · Resolution is a function of the square of each of the drivers, memory, connections, and pixels. · Insufficient data. Reliability for the glass is probably not severely impacted by resolution. Edge connections and drivers would be. Yield is greatly affected by resolution when number > 80 per inch are involved. · Don't know. · More drivers for high resolution. · Resolution correlates to reliability only to the extent that higher resolution panels have lower transmission which results in the need for more backlight power.			
7. What value of resolution would you recommend for the following types of display data based on cost and display performance criteria? (pixels/inch)			
a. Alphanumeric			
50	2	13.3	13.3
60	2	13.3	26.7
76	1	26.7	33.3
80	4	20.0	60.0
100	3	6.7	80.0
125	1	6.7	86.7
160 min	1	6.7	93.3
200	1	6.7	100.0
b. Graphic Data			
76	1	6.7	6.7
80	5	33.3	40.0
80 min.	1	6.7	46.7
100	4	26.7	73.3
150	1	6.7	80.0
160 min	1	6.7	86.7
200	2	13.3	100.0

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
c. Color Video			
76	1	6.7	6.7
80	3	20.0	26.7
80 min	1	6.7	33.3
82	1	6.7	40.0
100	3	20.0	60.0
120	1	6.7	66.7
140	1	6.7	73.3
150	2	13.3	86.7
160 min	1	6.7	93.3
200	1	6.7	100.0
d. Mono Video			7.1
76	1	7.1	21.4
120	2	14.3	42.9
140	3	21.4	57.1
150	2	14.3	78.6
160 min	3	21.4	85.7
164	1	7.1	92.9
180	1	7.1	100.0
200	1	7.1	
General Comments: · We are designing now with 6x8 VGA as adequate; 6-8 SVGA as more desirable. Sensors that give mono video are about the same. · We are using other techniques to improve apparent resolution. High resolution also brings a need for double width lines.			
8. What color pixel configuration is predominant in the current AMLCD market?			
a. Stripe (RGB)	8	61.5	N.A.
b. Triad (RGB)	2	15.4	
c. Square (RGBG)	3	23.1	
d. Other	0	0	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · Dominate Market Identification Stripe - TV - PC Laptop - Notebook PC Triad - Others - Video - Commercial Avionics Square - Avionics - Military Avionics Other - RGBG is also a pixel configuration			
9. Please list the relative advantages and disadvantages of the pixel configurations below. For instance, the triad configuration may be capable of higher resolution while the stripe configuration may be the least costly.			
Stripe	Advantages • Simple filter fabrication • Good for alphanumeric and graphics • Easy to manufacture • Easy to fabricate • High yield • Low cost • High volume • Efficient elect. interface	Disadvantages • Low resolution • More line outs • Poor image quality • Loss of horizontal resolution • Anti-Aliasing • Aliasing • More artifacts • Possible color fringing	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
Triad	Advantages • Higher resolution • Standard commercial drives • Good image quality • Lower pixel operative ratio • Good visual integration • Commercially available • Good for video images • Reduction in artifacts for video • Live video • Cost • Best pictorial presentations	Disadvantages • Staggered pixels more complex • More expensive • Odd correlation of image memory and LCD • Driver interface • Difficult to fabricate • Rotating images may not be acceptable • Low transmittance • Patterning & horizontal & vertical edges • Aliasing • Hurt readability for some shapes • Jagged on text & graphics • Most costly for lowest yield • Poor VGA compatibility	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
Square	Advantages • Best for color • Higher luminance & grey shades • Better than stripe • May give pixel redundancy • Good image quality • Easy to fabricate • No penalty on pixel aperture ratio • Higher resolution • Easier to control alias • Dual use color/mono • Good brightness • Visually almost as good as triad • Uniform resolution • Anti-aliasing • Double green • Better edges some shapes • Good VGA compatibility • High monochrome resolution	Disadvantages • Needs 4 elements per pixel • Increased TFT density • Lower cost to manufacture (?) • Different power requirements for green • Poor effective resolution • Not commercially available • Poorer image quality • Wastes some resolution • Color balance trade-off • Cost • Neither best color pictorial nor color graphics • Requires more memory • Requires more complex drive circuitry	
Other: RGBG Stripe	Advantages • Spatial matching to sensor data for wide-angle FLIR	Disadvantages • Lower aperture ratio than square	
Diagonal Mosaic	• High production yield	• Visible diagonal pattern • Poor VGA compatibility	
10. For the following display types, please specify the color pixel configuration you would recommend based on cost and performance criteria.			
a. Alphanumeric			N.A.
Stripe	8	53.3	
Square	7	46.7	
b. Graphics Disp.			
Stripe	5	31.3	N.A.
Frame Seq.	1	6.3	
Square	7	43.8	
Triad	3	18.8	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

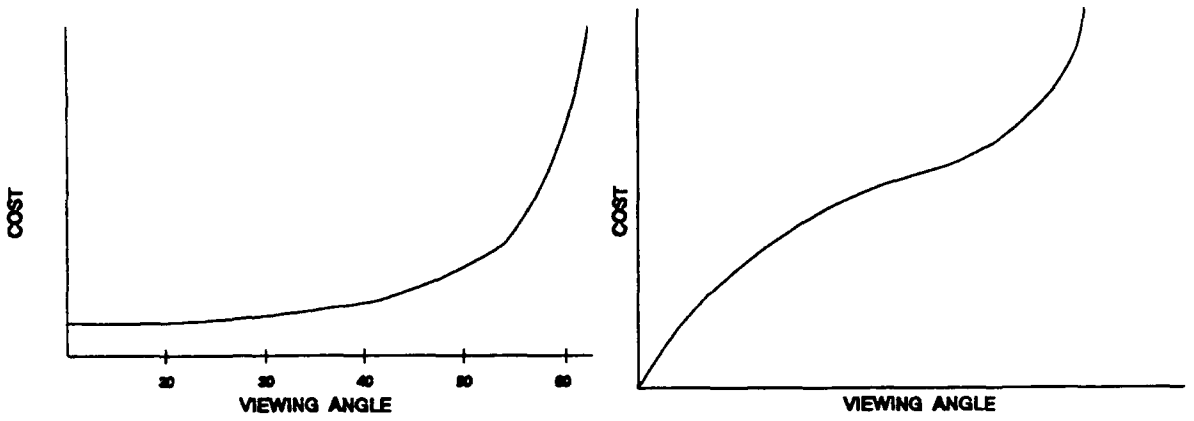
Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
c. Video Display			
Stripe	3	20.0	N.A.
Square	3	20.0	
Triad	7	46.7	
Triad/Quad	2	13.3	
d. Multifunction			
Stripe	4	25.0	N.A.
Square	7	43.8	
Triad	3	18.8	
Quad	2	12.5	
General Comments: · No preference. · Square if high resolution monochrome is needed, or low resolution color. · Alpha - mono square · Graphics - 80 square - 120 triad · Video - 128 triad · Multi - 80 quad 128 triad			
11. What is the widest horizontal viewing angle achievable by AMLCD technology under the brightest (worst case) lighting conditions encountered in airborne cockpits? (degrees off center)			
a. ± 20 °	2	12.5	100.0
b. ± 40 °	6	37.5	87.5
c. ± 60 °	3	18.8	50.0
d. ± 80 °	4	25.0	31.3
e. Other	1	6.2	6.3
e. ≤ 30 degrees off center			
General Comments · 60° but limited contrast · 60°-80° norm-black · 20°-40° norm-white. Compensated norm-white is on the way.			
12. Assuming the conditions and horizontal viewing angle selected in Question 11, what is the vertical viewing angle that can be achieved? (in degrees)			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
a. 10	1	6.3	100.0
+10/-30	1	6.3	93.7
20	1	6.3	87.5
25	2	12.5	81.3
+25/-10	1	6.3	68.8
30	4	25.0	62.5
45	3	18.8	37.5
55	1	6.3	18.8
60	2	12.5	12.5
General Comments: · About 45° but voltage adjustable · 80° for split pixel arrangement · 35° for graphics			
13. What function best describes the cost versus viewing angle curve for AMLCDs? (Sketch if possible)			
a. Linear	4	33.3	N.A.
b. Square Law	1	8.3	
c. Exponential	3	25.0	
d. Other	4	33.3	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
d. polynomial (3) no dependence			



General Comments:
- Exponential beyond 45°
- Cost of norm-white versus norm-black LCD construction
- Norm-white with compensating films may reduce this cost
- Slight dependence
- No dependence

14. What function best describes the reliability degradation versus the viewing angle curve for AMLCDs? (Please provide a sketch if possible)			
a. Linear	1	10.0	N.A.
b. Exponential	1	10.0	
c. Other	8	80.0	
c. (8) little or no effect			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · Backlight power dominates if cooling restricted. · Correlated only in the instance where high contrast is required over a large viewing angle (≤ 60°H) which requires high luminance at the outer angles. Luminance for the LCD falls as the angle from normal increases.			
15. Is it possible to offset the viewing angle from the center of the screen?			
a. Horizontal Plane b. Vertical Plane c. Both Planes	Yes / No 14 / 2 14 / 2 11 / 2	Yes / No 87.5 / 12.5 87.5 / 12.5 84.6 / 15.4	N.A.
General Comments: · Any change has more than one effect. · High cost for cockpit adjustable.			
16. Can the viewing angle offset be adjusted in the cockpit or must it be set at the maintenance facility or set at the time of manufacture?			
a. Cockpit Adjust b. Maintenance c. Manufacturer	5 4 6	33.3 26.7 40.0	N.A.
General Comments: · All. We are also looking at buying sets of displays in portrait mode for cross cockpit viewing - i.e., not interchangeable. · Is not an independent setting. Viewing angle is narrowed and shifted as a function of drive voltage, but other variables shift as well. This is probably most useful as a video interpretive knob.			
17. What contrast is achievable under the ambient conditions of 10,000 fc illumination (assumed over the full viewing angle identified in question 11)?			
a. 2.0 b. 3.0 c. 4.0 d. 5.0 e. Other	2 3 4 3 2	14.3 21.4 28.6 21.4 14.3	100.0 85.7 64.3 35.7 14.3
e. 7.0 8.0 white			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · 5.6 green · 3.5 red · 2.5 blue · Depends on the backlight, not AMLCD · This depends on background luminance which is a function of available power. Total reflectance is another key issue.			
18. What contrast is achievable under the ambient conditions of 8,000 fc and 500 fl of luminance (assumed over the full viewing angle identified in question 11)?			
a. 2.0	0	0	100.0
b. 3.0	3	21.4	100.0
c. 4.0	4	28.6	78.6
d. 5.0	5	35.7	50.0
e. Other	2	14.3	14.3
e. 6.0, 8.0			
General Comments: · See #17.			
19. What contrast is achievable under the ambient condition of 2,000 fc and 2,000 fl of luminance (assumed over the full viewing angle identified in question 11)?			
a. 2.0	2	15.4	100.0
b. 3.0	1	7.7	84.6
c. 4.0	2	15.4	76.9
d. 5.0	5	38.5	61.5
e. Other	3	23.1	23.0
e. 8.0, 10.0, 20.0			
General Comments: · See #17. · Specular at the specular angle depends on AR plus total reflectance. LCDs handle diffusion pretty well.			
20. What contrast is achievable under the ambient condition of 10,000 fc and 2,000 fl of luminance (assumed over the full viewing angle identified in question 11)?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
a. 2.0	4	28.6	100.0
b. 3.0	3	21.4	71.4
c. 4.0	3	21.4	50.0
d. 5.0	2	14.3	28.6
e. Other	2	14.3	14.3
e. 8.0, 10.0			
General Comments: · See #17. · 2.0 at 30°			
21. What contrast is achievable under the ambient condition of 10,000 fc illumination with the viewing angle identified in Question 11 and viewed directly on the centerline?			
a. 2.0	0	0	100.0
b. 3.0	1	6.7	100.0
c. 4.0	1	6.7	93.3
d. 5.0	4	26.7	86.7
e. Other	9	60.0	60.0
e. > 5.0, 5.66, 6.0, 8.0, (3) > 10.0, 15.0, 20-50			
General Comments: · See #17.			
22. What contrast is achievable under the ambient condition of 10,000 fc illumination with a narrow field of viewing angle (assume ±15° off center viewing field) and viewed directly on the centerline?			
a. 2.0	0	0	100.0
b. 3.0	0	0	100.0
c. 4.0	2	16.7	100.0
d. 5.0	3	25	83.3
e. Other	7	58.3	58.3
e. 5.66, 8.00, 10.0, (2) > 10.0, 15, 50			
General Comments: · See #17.			
23. What contrast do you feel is adequate for visual performance under the ambient conditions listed below?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
a. 10,000 fc			
2.0	1	8.3	8.3
3.0	3	25.0	33.3
4.0	2	16.7	50.0
5.0	3	25.0	75.0
6.0	1	8.3	83.3
8.0	2	16.7	100.0
b. 8,000 fc, 500 fl			
2.0	1	8.3	8.3
3.0	2	16.7	25.0
4.0	3	25.0	50.0
5.0	2	16.7	66.7
8.0	2	16.7	83.4
10.0	1	8.3	91.7
12.0	1	8.3	100.0
c. 2,000 fc, 2,000fl			
2.0	1	8.3	8.33
3.0	3	25.0	25.0
4.0	2	16.7	50.0
5.0	3	25.0	66.7
8.0	1	8.3	83.3
10.0	1	8.3	91.7
25	1	8.3	100.0
d. 10,000 fc, 3,000 fl			
3.0	3	27.3	27.3
4.0	2	18.2	45.5
4.66	1	9.1	54.6
5.0	3	27.3	81.8
8.0	1	9.1	90.9
20.0	1	9.1	100.0

General Comments:

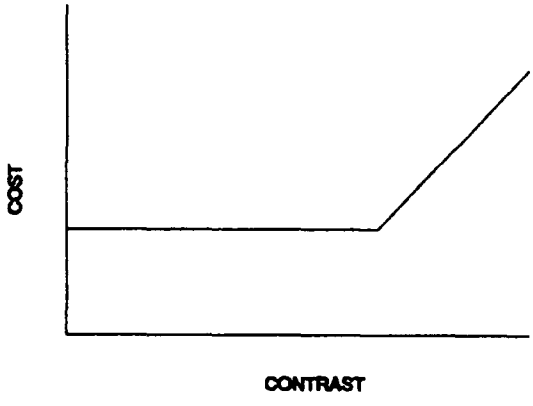
- See #17.
- Depends on graphics or video. Graphics use assumed (3.0).
- Depends on displayed information (4.0).
- 10.0 is desired (3.0).
- Graphics 4:1, video 5.66:1.

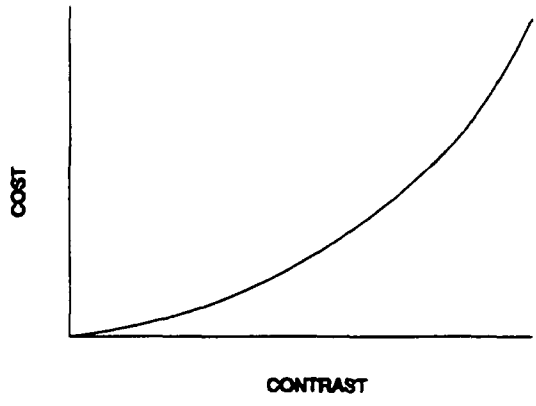
Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
24. If adequate contrast levels are not currently achievable, when do you believe the contrast capability will be met?			
current	2	18.2	18.2
a. 1 year	1	9.1	27.3
b. 2 years	0	0.0	27.3
c. 3 years	7	63.6	90.9
d. 5 years	1	9.1	100.0
e. > 5 years	0	0.0	100.0
General Comments: · (2) available now			
25. What function best describes the cost versus contrast curve for AMLCDs? (Sketch if possible)			
a. Linear	3	30.0	N.A.
b. Square Law	2	20.0	
c. Exponential	3	30.0	
d. Other	2	20.0	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
d. dog leg square root			





General Comments:

- Wide viewing will cost more but the overall acceptance performance determines the amount that has to be expended. This area has significant development work in process.
- Square root slightly dependence.
- This is a learning process. When people know how to do it, the cost will not necessarily be a direct function.
- This depends on the backlight

26. What function best describes the reliability degradation versus contrast curve for AMLCDs? (Sketch if possible)			
a. Linear	2	20.0	N.A.
b. Exponential	3	30.0	
c. Other	5	50.0	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

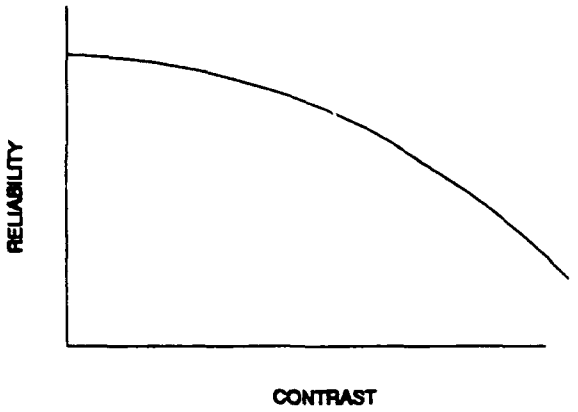
Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
c. Square Law (4) no dependencies  			
General Comments: · Higher temp leads to higher aging. · (3) not a direct function. · Backlight dissipation limited.			
27. What value of contrast would you recommend for the following ambient conditions based on cost and performance criteria?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
a. 10,000 fc			
2.0	1	8.3	8.3
3.0	1	8.3	16.7
4.0	3	25.0	41.7
5.0	2	16.7	58.3
6.0	1	8.3	66.7
7.0	1	8.3	75.0
8.0	2	16.7	91.7
5.0 - 20.0	1	8.3	100.0
b. 8,000 fc, 500 fl			
3.0	1	8.3	8.3
4.0	4	33.3	41.7
5.0	2	16.7	58.3
8.0	2	16.7	75.0
10.0	1	8.3	83.3
12.0	1	8.3	91.7
5.0-20.0	1	8.3	100.0
c. 2,000 fc, 2000 fl			
3.0	2	16.7	16.7
4.0	4	33.3	50.0
5.0	2	16.7	66.7
5.0-20.0	1	8.3	75.0
8.0	1	8.3	83.3
10.0	1	8.3	91.7
50	1	8.3	100.0
d. 10,000 fc, 2,000 fl			
3.0	1	9.1	9.1
4.0	4	36.4	45.5
4.66	1	9.1	54.6
5.0	2	18.2	72.7
8.0	1	9.1	81.8
5.0-20.0	2	18.2	100.0
General Comments: · See #17. · Graphics 4.0:1, video 5.66:1			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
28. What is the maximum luminance levels achievable with current AMLCD technology? (ft-Lamberts)			
a. 125-175 ft-L	3	23.1	100.0
b. 176-225 ft-L	4	30.8	76.9
c. 226-275 ft_L	2	15.4	46.2
d. 276-325 ft_L	3	23.1	30.8
e. Other	1	7.7	7.7
e. > 400			
General Comments: · This is a function of allowable power in the volume. Cooling air helps the issue of how much power you can dissipate without too high an internal temperature. · Any level depends on backlight. · 100 fl over complete viewing angle ≤ 60H, 0-30°V. · 10K fl, 10° viewing angle f 2.8 - subtractive color.			
29. Based of the following conditions: 1. maximum sunlight incident directly in the pilot's eyes, and 2. display located in shade on the cockpit panel What luminance level is required to provide adequate visual performance:			
a. 125-175 ft-L	2	13.3	13.3
b. 176-225 ft-L	8	53.3	66.7
c. 226-275 ft-L	1	6.7	73.4
d. 276-325 ft-L	2	13.3	86.7
e. Other	2	13.3	100.0
e. 300 fl, 3,500 fl			
General Comments: · 3,500 fl at CR=2, 10K Fc background luminance. · Not in aircraft applications.			
30. If current luminance levels are not capable of providing adequate visual performance, when do yo believe the luminance level will meet or exceed the requirement?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
current	4	44.4	44.4
a. 1 year	1	11.1	55.6
b. 2 years	1	11.1	66.7
c. 3 years	1	11.1	77.8
d. 5 years	1	11.1	88.9
e. > 5 years	1	11.1	100.0
General Comments: · (4) available now.			
31. What function best describes the cost versus luminance level for AMLCDs? (Sketch if possible)			
a. Linear	3	21.4	N.A.
b. Square Law	3	21.4	
c. Exponential	3	21.4	
d. Other	5	35.7	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

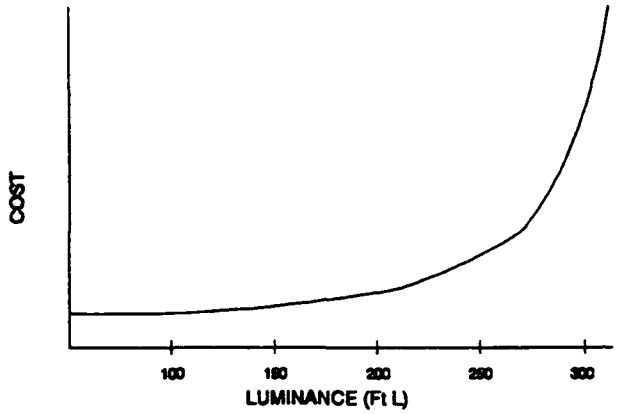
Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
d. (3) low correlation, polynomial, dog leg 			
General Comments: · Depends on backlight system (e.g., diffusion or projection). · Cost is in available cooling and is not a direct functional relationship except for a given system.			
32. What function best describes the reliability degradation versus luminance curve for AMLCDs? (Sketch if possible)			
a. Linear	3	25.0	N.A.
b. Exponential	7	58.3	
c. Other	2	16.7	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

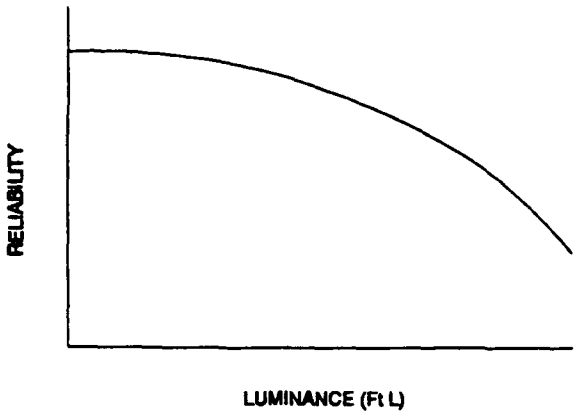
Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
c. (2) Square Law 			
General Comments: · As luminance goes up, the heat goes up and reliability goes down at least exponentially. · Dissipation limited. · High backlight intensities may affect polarizers and fade color filters. · Reliability will degrade with increased luminance due to increased power dissipation. However, reliability can be improved by reducing the viewing angle to concentrate luminance.			
33. What luminance levels would you recommend for the conditions stated in Question 29 based on cost and performance criteria?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
150	1	8.3	8.3
160	1	8.3	16.7
170	1	8.3	25.0
175	1	8.3	33.3
200	4	33.3	66.7
225	1	8.3	75.0
250	1	8.3	83.3
280	1	8.3	91.7
500	1	8.3	100.0
34. What ratio of full luminance to off is achievable with a single backlight system?			
a. 250:1	2	13.3	100.0
b. 500:1	2	13.3	86.7
c. 750:1	0	0.0	73.3
d. 1000:1	1	6.7	73.3
e. Other	10	66.7	66.7
e. (7) 2,000:1, 3,000:1, 4,000:1, 100:1			
General Comments: · An "off" AMLCD still leaks light making > 100:1 difficult. Also, it is independent of backlight luminance.			
35. What luminance degradation is achievable with current backlighting technology?			
a. 5% -10,000 hr	1	7.1	7.1
a. 10% -10,000 hr	2	14.3	21.4
a. 20% -10,000 hr	2	14.3	35.7
a. 30% -10,000 hr	7	50.0	85.7
e. Other	2	14.3	100.0
e. 5% in 1,000 hours, 100% in 3,000 hours			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · NB current philosophy is to replace at 1,000 hours. · 25% of peak average luminance level (C). · 30% is present case. · 2,000 hour life total for a tube. · 5% in 10,000 hours after burn-in. · Current florescent bulbs wear out at 3,200 hours. Curves show degradation down to 30% in a linear fashion, then bulb mortality swamps out degradation.			
36. What luminance variation (of like symbols or areas) is achievable across the usable area of the display?			
a. ± 5%	2	11.8	11.8
b. ± 10%	5	29.4	41.2
c. ± 20%	4	23.5	64.7
d. ± 30%	4	23.5	88.2
e. Other	2	11.8	100.0
e. ± 15%, ± 40%			
General Comments: · Measurement spot size is critical for this information to be useful. Our numbers reflect F-22 measurement size. (≤ 4% without a large change in optical efficiency. Of course, any uniformity can be achieved with additional depth and diffusers at the expense of efficiency.) · 5% may result in low luminance.			
37. What luminance variation within a 0.5 inch diameter circle is achievable?			
a. ± 2.5%	11	64.7	64.7
b. ± 5.0%	3	17.7	82.4
c. ± 7.5%	0	0.0	82.4
d. ± 10.0%	3	17.7	100.0
e. Other	0	0.0	N.A.
38. For the two conditions stated in Questions 36 and 37, what percentage of luminance variation do you feel is at the levels of human perception with respect to detecting differences in luminance levels?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
a. Across entire screen			
0.5	1	6.3	6.3
5	2	12.5	18.8
10	2	12.5	31.3
15	2	12.5	43.8
20	3	18.8	62.5
25	2	12.5	75.0
15-30	1	6.3	81.3
30	1	6.3	87.5
40	1	6.3	93.7
50	1	6.3	100.0
b. Within 0.5 inch circular area			
0.5	1	6.3	6.3
1	1	6.3	12.5
2	1	6.3	18.8
2.5	5	31.3	50.0
3.5	1	6.3	56.3
5	3	18.8	75.0
10	1	6.3	81.3
15	2	12.5	93.7
20	1	6.3	100.0
General Comments: · Alphanumeric variations can be higher than graphics/video (40% versus 25%).			
39. If current luminance variation levels are not capable of meeting the levels stated in Question 38, when do you believe the luminance variation levels will meet or exceed the requirement?			
current	3	37.5	37.5
a. 1 year	0	0.0	37.5
b. 2 years	3	37.5	75.0
c. 3 years	1	12.5	87.5
d. 5 years	1	12.5	100.0
e. > 5 years	0	0.0	N.A.
General Comments: · Alphanumeric available now. Video/graphics in 2 years.			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
40. What function best describes the cost versus luminance curve for AMLCDs? (Sketch if possible)			
a. Linear	3	27.3	N.A.
b. Square Law	4	36.4	
c. Exponential	2	18.2	
d. Other	2	18.2	
d. (2) low correlation			
General Comments: · Statistical control and large volumes can reduce the yield uncertainty. · Backlight dependent			
41. What luminance variation levels would you recommend for the conditions below based on cost and performance criteria?			
a. Across entire screen			
1	1	7.1	7.1
5	2	14.3	21.4
10	1	7.1	28.6
15	2	14.3	42.9
20	4	28.6	71.4
30	2	14.3	85.7
40	1	7.1	92.9
50	1	7.1	100.0
b. Within 0.5 inch circular area			
0.2	1	6.7	6.7
1	1	6.7	13.3
2	2	13.3	26.7
2.3	2	13.2	40.0
2.5	3	20.0	60.0
5	3	20.0	80.0
10	1	6.7	86.7
15	1	6.7	93.3
20	1	6.7	100.0
42. What is the maximum number of gray shade levels possible given current technology and materials used in the AMLCD field?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
a. 16 levels	1	6.7	100.0
b. 32 levels	3	20.0	93.3
c. 64 levels	7	46.7	73.3
d. 128 levels	1	6.7	26.7
e. Other	3	20.0	20.0
e. 8 levels over entire viewing angle (2) 256			
General Comments: · Drivers for 64 shades are under development. Dithering can give 204 multiples more.			
43. What do you think is the maximum number of discernible (based on human perception) gray shade levels for AMLCD technology for these data display types?			
a. Alphanumeric			
4	2	13.3	13.3
8	5	33.3	46.7
16	5	33.3	80.0
32	1	6.7	86.7
64	1	6.7	93.3
300	1	6.7	100.0
b. Graphic Data			
2-6	1	6.7	6.7
8	3	20.0	26.7
8-16	1	6.7	33.3
16	4	26.7	60.0
32	1	6.7	66.7
64	2	13.3	80.0
128	2	13.3	93.3
300	1	6.7	100.0
c. Color Video			
14	1	7.1	7.1
16	1	7.1	14.3
32	3	21.4	35.7
64	4	28.6	64.3
128	3	21.4	85.7
256	1	7.1	92.9
300	1	7.1	100.0

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
d. Mono Video			
8	1	6.7	6.7
14	1	6.7	13.3
16	2	13.3	26.7
32	2	13.3	40.0
64	4	26.7	66.7
128	2	13.3	80.0
128-256	1	6.7	86.7
256	1	6.7	93.3
300	1	6.7	100.0
44. If the current gray shade level capability is below the number of discernible levels based on human perception, when do you believe the level of gray shading will meet of exceed the requirement?			
a. 1 year	2	20.0	20.0
b. 2 years	4	40.0	60.0
c. 3 years	2	20.0	80.0
d. 5 years	0	0.0	80.0
e. > 5 years	2	20.0	100.0
General Comments: · Need a good commercially available driver. · Many of the 256 levels are too close to be useful at the high end, too far apart at the low end.			
45. What function best describes the cost versus gray shade level curve for AMLCDs? (Sketch if possible)			
a. Linear	5	35.7	N.A.
b. Square Law	1	7.1	
c. Exponential	5	33.7	
d. Other	3	21.4	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

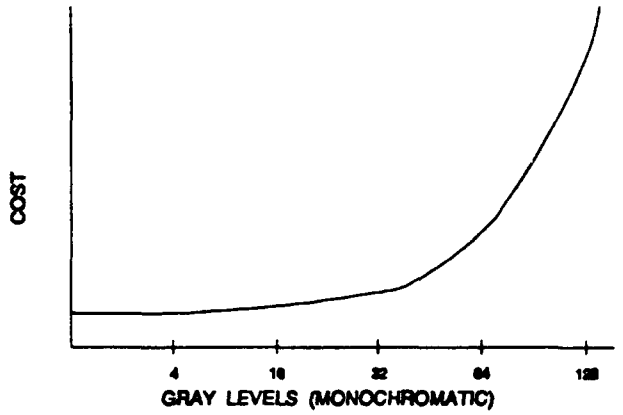
Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
d. No dependence, Polynomial, Dog leg 			
General Comments: · Cost is very high today. It will be much less once the key developments are achieved. · Driver costs more closely correlate to the number of outputs per driver and the tolerance on each level. There is currently a wide spread on gray scale costs.			
46. What function best describes the reliability degradation versus gray shade curve for AMLCDs? (Sketch if possible)			
a. Linear b. Exponential c. Other	4 3 5	33.3 25.0 41.7	N.A.
c. (2) Square Law (2) No correlation Slight variation			
General Comments: · Slight variation based on more complicated driver ICs for more gray shades. · Not directly available.			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
47. For the following display types, please specify the number of gray shades you would recommend based on cost and performance criteria?			
a. Alphanumeric			
2	3	21.4	21.4
4	3	21.4	42.9
8	7	50.0	92.9
64	1	7.1	100.0
b. Graphic Data			
2	1	7.1	7.1
4	2	14.3	21.4
8	3	21.4	42.9
16	5	35.7	78.6
64	2	14.3	92.9
128	1	7.1	100.0
c. Color Video			
16	1	7.1	7.1
>16	1	7.1	14.3
32	3	21.4	35.7
64	6	42.9	78.6
128	3	21.4	100.0
d. Mono Video			
>16	1	7.1	7.1
32	3	21.4	28.6
64	5	35.7	64.3
128	4	28.6	92.9
256	1	7.1	100.0
48. Is it possible to match the gray shade luminance levels to the Munsell value scale rather than space the levels linearly?			
Yes	11	91.7	N.A.
No	1	8.3	

General Comments:

- To match the Munsell scale, you need to be within a very limited viewing angle.
- Setting gray shade levels to most curves is relatively easy. However, we have shown that most curves that are similar to a logarithmic curve, such as the Munsell, are virtually indistinguishable without side-by-side comparison.
- They should not be spaced linearly but with a gamma function.

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
49. What chromaticity deviation limits are achievable for any 0.5 inch diameter circular area on the surface of a given display module based on units on the 1976 CIE UCS?			
a. < 0.015 unit	5	33.3	33.3
b. < 0.025 unit	7	46.7	80.0
c. < 0.035 unit	2	13.3	93.3
d. Other	1	6.7	100.0
d. 0.05			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
50. What is the chromaticity deviation limit achievable between any given display module and a selected standard chromaticity based on units on the 1976 CIE UCS?			
a. < 0.015 unit	1	7.1	7.1
b. < 0.025 unit	3	21.4	28.6
c. < 0.035 unit	9	64.3	92.9
d. Other	1	7.1	100.0
d. much > 0.035			
General Comments: · .015 in limited production. · The deviation is less if the areas of interest are adjacent.			
51. What do you think the maximum chromaticity deviation (based on units of the 1976 CIE UCS) is before a discernible color difference occurs for the three primary colors:			
a. Red			
0.015	3	23.1	23.1
0.02	4	30.8	53.9
0.025	2	15.4	69.2
0.03	3	23.1	92.3
0.04	1	7.7	100.0
b. Green			
0.01	2	15.4	15.4
0.015	2	15.4	30.8
0.02	2	15.4	46.2
0.025	3	23.1	69.2
0.03	3	23.1	92.3
0.035	1	7.7	100.0
c. Blue			
0.01	1	7.7	7.7
0.015	1	7.7	15.4
0.02	1	7.7	23.1
0.025	1	7.7	30.8
0.03	6	46.2	76.9
0.035	2	15.4	92.3
0.05	1	7.7	100.0

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
52. If the current chromaticity deviations are greater than levels identified in Question 51, when do you believe the deviation levels will meet or exceed the requirement?			
current	5	50.0	50.0
a. 1 year	0	0.0	50.0
b. 2 years	0	0.0	50.0
c. 3 years	3	30.0	80.0
d. 5 years	1	10.0	90.0
e. > 5 years	1	10.0	100.0
General Comments: · 5 can currently meet.			
53. What function best describes the cost versus chromaticity deviation curve for AMLCDs? (Sketch if possible)			
a. Linear	2	25.0	N.A.
b. Square Law	0	0.0	
c. Exponential	4	50.0	
d. Other	2	25.0	
d. (2) no correlation			
General Comments: · Learning process primarily driven by the commercial world. · Small quantities - none > 50 Large quantities - > 500 This requires that the lamps and the LCD stack-up have tight lot-to-lot control.			
54. For the following primary colors, please specify the chromaticity deviation you would recommend based on cost and performance criteria?			
a. Red			
0.01	1	8.3	8.3
0.015	1	8.3	16.7
0.02	1	8.3	25.0
0.03	5	41.7	66.7
0.035	1	8.3	75.0
0.04	1	8.3	83.3
0.05	1	8.3	91.7
0.3	1	8.3	100.0

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
b. Green			
0.01	1	7.7	7.7
0.015	1	7.7	15.4
0.02	1	7.7	23.1
0.03	5	38.5	61.5
0.035	2	15.4	76.9
0.05	2	15.4	92.3
0.3	1	7.7	100.0
c. Blue			
0.01	1	9.1	9.1
0.015	1	9.1	18.2
0.02	1	9.1	27.3
0.025	1	9.1	36.4
0.03	5	45.5	81.8
0.05	2	18.2	100.0
General Comments: · Display to display 0.25 - (0.015 within a display).			
55. For the primary colors, please specify the largest difference in percent of maximum intensities. For instance, if green will yield the maximum intensity, what percentage below this intensity is red and blue. Please indicate the color with the maximum intensity.			
a. Red b. Green c. Blue	Red Green Blue 80 100 60 70 100 82 68 100 78 64 100 32 50 100 35 45 100 15 42 100 25	N.A.	N.A.
General Comments: · This question cannot be answered independent of the chromaticity. The color palette and intensity are functions of the LCD primary spectral transmissions and the lamp spectral emissions. The two variables can be balanced to provide a wide range of results, all of which may be acceptable.			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
56. Can you meet the NVIS radiance maximums specified for Types I and II, Class A or Class B in MIL-L-85762 for color AMLCDs?			
Class A			N.A.
Yes	8	61.5	
No	5	38.5	
Class B			N.A.
Yes	12	92.3	
No	1	7.7	
General Comments: · Yes - with no red emission. · Yes - with limited red. · For 611 nm, fully saturated reds for use during Class A NVIS can only barely be met with a theoretical perfect filter. However, Class A can be met with degraded color set such as using a reddish orange color. · 3 out of 15 vendors say they can. · (3) color Class A never.			
57. If you cannot meet current NVIS requirements, when do you think you will be able to?			
a. 1 year	1	N.A.	N.A.
58. How would the NVIS radiance maximums specified for Types I and II, Class A or Class B in MIL-L-85762 be met?			
a. Separate NVIS Backlight	2	25.0	N.A.
b. Additional Filters	2	12.5	
c. Both a. and b.	5	50.0	
d. Other	1	12.5	
d. Not in MIL-Spec applications.			
General Comments: · Monochrome only needs filters. · Additional filters may not be allowed operationally. · Depends on the program requirements.			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
59. For a given display, how costly (in terms of % increase) would it be to achieve NVIS compatibility?			
a. Class A			
2	1	10.0	100.0
10	1	10.0	90.0
13	1	10.0	80.0
15	4	40.0	70.0
20	2	20.0	30.0
Not Achievable	1	10.0	20.0
b. Class B			
Small	1	10.0	100.0
2	1	10.0	90.0
10	5	50.0	80.0
15	1	10.0	30.0
20	2	20.0	20.0
General Comments: · This is driven by program requirements and can change drastically. · There are system costs to deal with a limited color palette when operated in the NVIS mode. · 1,000/box = 2%.			
60. If the NVIS hardware is add-on instead of built-in, how long will it take (in minutes) to modify the display for a NVIS mission?			
a. Class A			
1	2	50	50
20	1	25	75
30	1	25	100
b. Class B			
1	2	50	50
20	1	25	75
30	1	25	100
c. Not Achievable	4	N.A.	N.A.

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · Excellent idea, would reduce costs enormously. · Add-on hardware not liked, preference for built-in solution. · We are striving for a simple switch that operates right away.			
61. Will converting a display to become NVIS compatible require removal of the display from the aircraft?			
Yes	9	69.2	N.A.
No	4	30.8	
General Comments: · No - with add-on filters.			
62. What is the maximum achievable update rate for current AMLCD technology and materials?			
a. 15 Hz	0	0.0	100.0
b. 30 Hz	2	13.3	100.0
c. 45 Hz	0	0.0	86.7
d. 60 Hz	10	66.7	86.7
e. Other	3	20.0	20.0
e. 80, 100, 120			
General Comments: · Size dependent. · If video is 60 Hz, AMLCD should be 60 Hz to prevent motion artifacts.			
63. What do you believe will be the maximum achievable update rate for AMLCD technology and materials in 5 years?			
a. 45 Hz	0	0.0	100.0
b. 60 Hz	3	25.0	100.0
c. 75 Hz	2	16.7	75.0
d. 90 Hz	3	25.0	58.3
e. Other	4	33.3	33.3
e. 100, 120, (2) 180			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · 120 already applied by US in standard LCD stereo refueling system first used in 1988. · This is not an area that is currently being pushed by manufacturers. · Update rate is highly dependent on the operating temperature range and the physical properties of the LCD material.			
64. What function best describes the cost versus update rate for AMLCDs? (Sketch if possible)			
a. Linear	3	27.3	N.A.
b. Square Law	2	18.2	
c. Exponential	2	18.2	
d. Other	4	36.4	
d. Slight dependence, Staircase, Polynomial, No correlation			

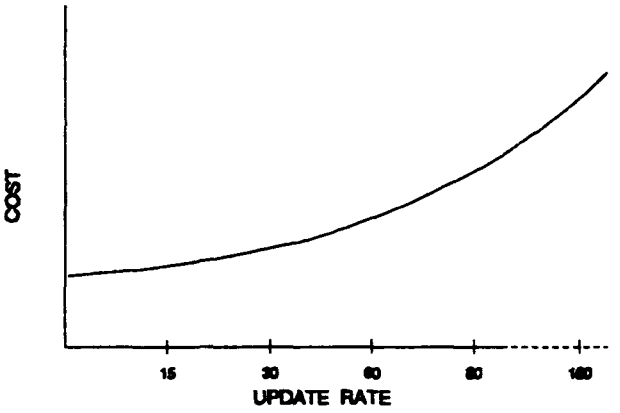


Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · Limited by source driver clocking rate. Must partition display into source groups with one video input per group. Step function occurs where additional input required.			
65. What function best describes the reliability degradation versus update rate for AMLCDs? (Sketch if possible)			
a. Linear	4	40.0	N.A.
b. Exponential	1	10.0	
c. Other	5	50.0	
c. Square Law Staircase (2) slight dependence None			
66. What is the minimum achievable response times (rise & fall times) of individual pixels in AMLCDs at 25°C?			
a. 2 milliseconds	1	6.3	6.3
b. 5 milliseconds	1	6.3	12.5
c. 10 milliseconds	4	25.0	37.5
d. 20 milliseconds	3	18.8	56.3
e. Other	7	43.8	100.0
e. (2) 15, (4) 30, 66			
General Comments: · Depends on gray levels. · 10%-90% transition limited operation range gray scale response is much slower (b).			
67. What is the maximum refresh rate that can be achieved using the pixel response time of Question 66?			
a. 60 Hz	8	53.3	100.0
b. 90 Hz	3	20.0	46.7
c. 120 Hz	3	20.0	26.7
d. 150 Hz	0	0.0	6.7
e. Other	1	6.7	6.7
e. 80 Hz			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · Refresh rate can be selected somewhat independently of fluid response time. · Depends on number of lines.			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
68. What refresh rate do you feel is adequate to remove the perception of flicker in AMLCD displays in the dynamic aircraft environment?			
a. 60 Hz	9	64.3	64.3
b. 90 Hz	3	21.4	85.7
c. 120 Hz	1	7.1	92.9
d. 150 Hz	0	0.0	92.9
e. Other	1	7.1	100.0
e. 30			
69. If adequate refresh rates are not currently achievable, when do you believe the refresh rates will be met?			
current	3	50.0	50.0
a. 1 year	0	0.0	50.0
b. 2 years	0	0.0	50.0
c. 3 years	2	33.3	83.3
d. 5 years	1	16.7	100.0
e. > 5 years	0	0.0	100.0
General Comments: · 3 can currently achieve.			
70. What function best describes the cost versus response times for individual pixels in an AMLCD? (Sketch if possible)			
a. Linear	2	18.2	N.A.
b. Square Law	1	9.1	
c. Exponential	5	45.4	
d. Other	3	27.3	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

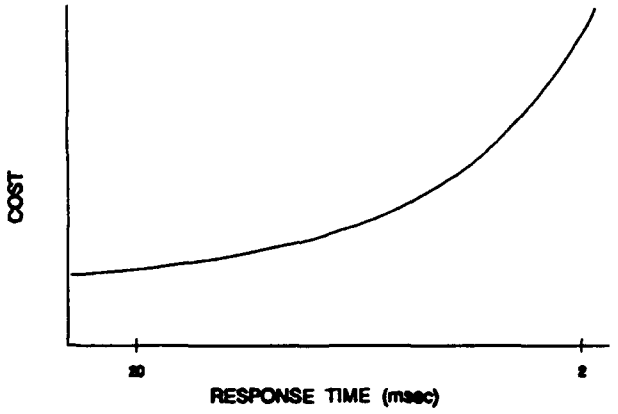
Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
d. (2) slight dependence No correlation  			
General Comments: · 10%-90% full on/full off. · This is at best a big unknown whether response times less than 15 ms are achievable without sacrificing other critical parameters such as contrast. This is a LC material problem. · Improvement requires faster LC materials that do not impact other parameters. · 10 ms breakpoint - below this, costs increase dramatically.			
71. What response times would you recommend based on cost and performance criteria?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
10	1	7.1	7.1
15	1	7.1	14.3
<20	1	7.1	21.4
20	7	50.0	71.4
30	1	7.1	78.6
33	1	7.1	85.7
35	1	7.1	92.9
75	1	7.1	100.0
General Comments: · 25 at 45°C.			
72. What is the minimum reflectance achievable off of all the combined surfaces of the active display area of an AMLCD module?			
a. less than 0.5%	5	33.3	33.3
b. less than 1.0%	4	26.7	60.0
c. less than 1.5%	3	20.0	80.0
d. less than 2.0%	1	6.7	86.7
e. Other	2	13.3	100.0
e. (2) 5.0%			
General Comments: · Monochrome will be lower (b). · Depends on type of glass. · Pixel density. · Diffused rather than specular light = 0.5%.			
73. What do you believe will be the minimum reflectance achievable off of all the combined surfaces of an AMLCD module in 5 years?			
a. less than 0.2%	1	7.1	7.1
b. less than 0.3%	2	14.3	21.4
c. less than 0.5%	6	42.9	64.3
d. less than 1.0%	3	21.4	85.7
e. Other	2	14.3	100.0
e. (2) < 2.0%			
74. What is the minimum percentage of subpixel defects that can be reasonably attained in a production run with current AMLCD processes and materials?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
a. 0.005%	3	25.0	41.7
b. 0.010%	4	33.3	75.0
c. 0.015%	2	16.7	91.7
d. 0.020%	1	8.3	100.0
e. Other	2	16.7	16.7
e. < 0.005% 0.002%			
General Comments: · This depends on whether you are willing to trade away other characteristics, such as transmission. Example: Sharp displays commonly found with zero defects with their TFT design. However, you trade off many critical parameters.			
75. What function best describes the cost versus subpixel defect percentage for AMLCDs? (Sketch if possible)			
a. Linear	1	11.1	N.A.
b. Square Law	1	11.1	
c. Exponential	7	77.8	
d. Other	0	0.0	
General Comments: · Subpixel defects are a matter of volume and process.			
76. What is the minimum percentage of subpixel defects that you feel can be obtained with AMLCD processes and materials in 5 years?			
a. 0.002	3	30.0	50.0
b. 0.003	2	20.0	70.0
c. 0.005	2	20.0	90.0
d. 0.010	1	10.0	100.0
e. Other	2	20.0	20.0
e. (2) .001			
77. What is the highest attainable ratio of display area (in square inches) to cluster defects that can be currently achieved with AMLCDs?			
a. 16:1	0	0.0	12.5
b. 25:1	1	12.5	12.5
c. 36:1	2	25.0	37.5
d. 64:1	3	37.5	75.0
e. Other	2	25.0	100.0

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
e. (2) 4:1			
General Comments: · Cluster defects are more noticeable than single pixel out and should be eliminated.			
78. Assuming adequate heater power is available and that thermally induced stresses are the determining factor, what is the minimum warm-up time from -55oC that current AMLCD materials will require to achieve full specification performance?			
a. 2 minutes	4	30.8	30.8
b. 3 minutes	0	0.0	30.8
c. 4 minutes	0	0.0	30.8
d. 5 minutes	6	46.2	76.9
e. Other	3	23.1	100.0
e. (2) 10 minutes 15 minutes			
General Comments: · Not applicable for out application. · System issue, not a component issue. · 2 minutes is possible, but > 5 minutes is desirable. There are trade offs to achieve 2 minutes. · Florescent tubes are the limiting factor not LCD response time.			
79. What are the minimum operating temperatures for the materials used in current AMLCDs?			
a. -55oC	5	31.3	31.3
b. -40oC	1	6.3	37.5
c. -25oC	2	12.5	50.0
d. -10oC	6	37.5	87.5
e. Other	2	12.5	100.0
e. (2) 0°C			
General Comments: · 0°C is the minimum uniform striking temperature for fluorescent lights. · -55°C w/heater, 10°C w/o heater. · With heaters.			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

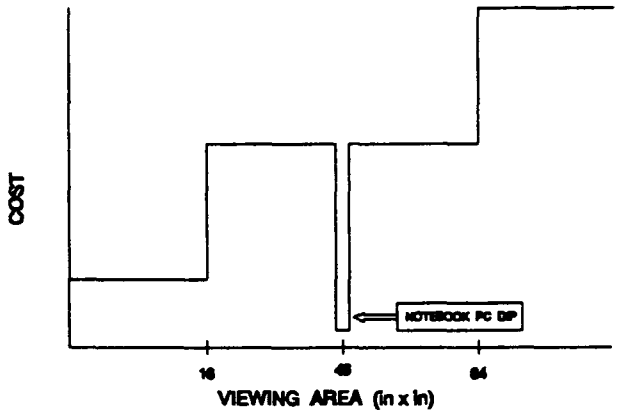
Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
80. What are the maximum operating temperatures for the materials used in current AMLCDs?			
a. +125°C	0	0.0	0
b. +100°C	2	13.3	13.3
c. +75°C	8	53.3	66.7
d. +50°C	2	13.3	80.0
e. Other	3	20.0	100.0
e. (2) 85°C, 93°C			
General Comments: · 50°C ambient (not LCD temp.). · 100° LCD temp - short duration.			
81. What are the minimum and maximum storage temperatures for the materials used in AMLCDs? (Note: The display must survive the temperature range but not operate at this range)			
a. Minimum (°C)			
-64	1	6.7	6.7
-60	2	13.3	20.0
-62	1	6.7	26.7
-55	9	60.0	86.7
-40	2	13.3	100.0
b. Maximum (°C)			
85	3	20.0	100.0
90	3	20.0	80.0
93	1	6.7	60.0
95	3	20.0	53.3
100	3	20.0	33.3
125	2	13.3	13.3
General Comments: · Full MIL-Spec is our desire (-55,125); something less will be our compromise. · 95° for less than 1,000 hours.			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
82. What weights, in pounds per square inch of viewing area size, are achievable with current AMLCD materials?			
a. 0.05 lbs/in^2	2	33.3	33.3
b. 0.10 lbs/in^2	1	16.7	50.0
c. 0.15 lbs/in^2	1	16.7	66.7
d. 0.20 lbs/in^2	1	16.7	83.3
e. Other	1	16.7	100.0
e. < 0.05			
General Comments: · "Dumb terminal" video input, no graphics processor (d). · Program requirement dependent. · Glass and drivers only (a).			
83. What is the maximum viewing area, in square inches, that is achievable with current AMLCD technology?			
a. 64 in^2	4	25.0	100.0
b. 100 in^2	5	31.3	75.0
c. 144 in^2	4	25.0	43.8
d. 225 in^2	1	6.3	18.8
e. Other	2	12.5	12.5
e. 139 in^2 250 in^2			
General Comments · We are striving for 49 sq in with SVGA. Our next increment is probably 96 sq in combining two display heads. Out 2015 AD goal is a 1 meter diagonal.			
84. What function best describes that cost versus viewing area for AMLCDs? (Sketch if possible)			
a. Linear	3	21.4	N.A.
b. Square Law	5	35.7	
c. Exponential	3	21.4	
d. Other	3	21.4	

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
d. (2) polynomial Staircase			



General Comments:

- Limited by available production equipment handling of substrate. Up to 12" diagonal is linear (a).
- Bumpy curve relating to vendor investment - it appears to be stuck at 10" to 15" diagonal for the 1990s.

85. What function best describes the reliability degradation versus viewing area for AMLCDs? (Sketch if possible)			
a. Linear	6	60	N.A.
b. Exponential	3	30	
c. Other	1	10	
c. None			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
86. What is maximum mean time between failure (MTBF) that can be achieved with current AMLCD technology for the following display types? (Assume that backlight degradation is not considered a failure.)			
Type I			
Resolution			
50	1	10.0	100.0
60	2	20.0	90.0
80	4	40.0	70.0
100	1	10.0	30.0
128	2	20.0	20.0
Viewing Angle			
10	1	10.0	100.0
15	1	10.0	90.0
20	1	10.0	80.0
25	1	10.0	70.0
30	2	20.0	60.0
40	2	20.0	40.0
60	2	20.0	20.0
MTBF			
a. 2,500 hr	0	0	100.0
b. 5,000 hr	0	0	100.0
c. 7,500 hr	2	20.0	100.0
d. 10,000 hr	6	60.0	60.0
e. Other	2	20.0	20.0
e. 15,000 hr, 20,000 hr			
Type II			
Resolution			
80	6	60.0	100.0
85	1	10.0	40.0
90	1	10.0	30.0
100	2	20.0	20.0

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
Type II (cont)			
Viewing Angle			
20	1	10.0	100.0
25	2	20.0	90.0
30	2	20.0	70.0
40	2	20.0	50.0
60	1	10.0	30.0
90	2	20.0	20.0
MTBF			
a. 2,500 hr	0	0	100.0
b. 5,000 hr	5	50.0	100.0
c. 7,500 hr	1	10.0	50.0
d. 10,000 hr	3	30.0	40.0
e. Other	1	10.0	10.0
e. 20,000 hr			
Type III			
Resolution			
64	1	12.5	100.0
80	3	37.5	87.5
100	1	12.5	50.0
120	1	12.5	37.5
151	2	25.0	25.0
Viewing Angle			
20	1	12.5	100.0
30	2	25.0	87.5
45	2	25.0	62.5
60	2	25.0	37.5
120	1	12.5	12.5
MTBF			
a. 2,500 hr	3	37.5	100.0
b. 5,000 hr	1	12.5	62.5
c. 7,500 hr	1	12.5	50.0
d. 10,000 hr	3	37.5	37.5
e. Other	0	0.0	0.0

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses	Percentage of Responses	Cumulative Percentage of Responses
General Comments: · All values depend on available cooling. · Environmental temp has a much bigger impact than any of the things you specified.			
87. Please rank the following characteristics according to their cost impact (top 5 only, number 1 being highest cost driver).			
	Score / Rank	N.A.	N.A.
Resolution	49 / 2		
Viewing Angle	27 / 4		
Contrast	12 / 7		
Luminance	25 / 5		
Gray Shades	12 / 7		
Chromaticity Deviation	6 / 10		
NVIS	10 / 9		
Time Based Eff.	5 / 11		
Display Defects	37 / 3		
Size	53 / 1		
Reliability	0 / 12		
Color/Mono	19 / 6		
88. Please rank the following characteristics according to their reliability impact (top 5 only, number 1 being highest degradation factor).			
	Score / Ranking	N.A.	N.A.
Resolution	45 / 1		
Viewing Angle	1 / 12		
Contrast	14 / 7		
Luminance	44 / 2		
Gray Shades	25 / 4		
Color/Mono	8 / 8		
Chromaticity Deviation	4 / 10		
NVIS	2 / 11		
Time Based Eff.	19 / 5		
Display Defects	13 / 6		
Size	33 / 3		
Interconnections	5 / 9		
89. Will current AMLCDs be able to meet the vibration levels encountered in the following aircraft environments?			

Table 4-1. AMLCD Industry Survey Results (Cont'd)

Question/ Answers	Number of Responses		Percentage of Responses		Cumulative Percentage of Responses
	Yes	No	Yes	No	N.A.
a. Jet Aircraft	15	0	100.0	0.0	
b. Prop Aircraft	12	0	100.0	0.0	
c. Rotor Aircraft	13	1	92.9	7.1	

5.0 SUMMARY

This survey investigated resolution, pixel configuration, viewing angle, contrast, gray shades, luminance, chromaticity, NVIS compatibility, time based defects, display effects, display size, mean time between failure, and cost analysis in terms of AMLCD technology. Sections 5.1 through 5.13 briefly summarize the results received from each question in the different sections of the survey.

5.1 Resolution

According to the majority of the survey results, current AMLCD technology is capable of producing 120 pixels per inch for color and between 200 and 300 for monochrome. When considering human perception limits, 100 to 140 pixels per inch would be adequate for alphanumeric, graphic, and color video data; between 140 and 200 pixels per inch would be adequate for monochrome data. Many comments were received stating that these resolution values vary greatly with viewing distance and display contents.

Most respondents stated that technology to achieve the desired resolutions currently exists. However, others stated it would take as long as 5 years to develop adequate technology. Resolution was listed as a high cost driver and thought to be exponentially related to cost. While some respondents stated reliability degradation is not affected by resolution others indicated an exponential relationship. One graph puts 150 to 200 pixels per inch as a point of increased degradation on an exponential curve. When cost was considered, resolution recommendations were 50 to 100 pixels per inch for alphanumeric data, 80 to 100 for graphic data, 80 to 150 for color video data, and 140 to 160 for monochrome video data.

5.2 Pixel Configuration

Most survey results indicated the stripe color pixel configuration is the most common in the current AMLCD market due to its use with laptop personal computers and televisions. Many indicated the stripe configuration is advantageous because it is easy to manufacture and has low cost, however, many cited low resolution and anti-aliasing as disadvantages. The triad configuration was said to present higher resolution and was good for video, however, it is more expensive and more difficult to fabricate. Square configuration was stated to have many advantages, such as higher resolution, luminance and grey shades, anti-aliasing, as well as good brightness; however, it is costly due to its high memory requirement and complex driver circuitry. Many respondents felt the square configuration was good for commercial and military avionics environments. Other pixel configurations suggested were RGBG stripe and diagonal mosaic. For use in alphanumeric displays, stripe and square where selected most. Square dominated graphic display selection, however, stripe and triad were also chosen. Triad was selected most often, for video display. For multi-function displays (color and monochrome), the square pixel configuration was also chosen most often.

5.3 Viewing Angle

The survey results indicated the horizontal viewing angle achievable by current AMLCD technology in an airborne cockpit is between ± 40 and ± 80 degrees off center. The most commonly selected vertical viewing angles were 30 and 45 degrees. (Survey responses indicated some confusion over the "plus or minus off of centerline" convention used in this survey). Many indicated that cost was linearly related to the viewing angle, however, others stated it was an exponential relationship. Most also stated that viewing angle did not affect reliability degradation. A majority answered that it was possible to offset the viewing angle from the center of the screen in the horizontal and vertical planes. Responses which specified where the viewing angle could be adjusted were split between in the cockpit, at the manufacturer, and as a maintenance action.

5.4 Contrast

Most respondents indicated that a contrast of 4.0 was achievable under ambient conditions of 10,000 fc illumination; 4.0 or 5.0 was achievable under ambient conditions of 8,000 fc and 500 fl of luminance; 5.0 was achievable under ambient conditions of 2,000 fc and 2,000 fl of luminance; and 2.0 or 3.0 was achievable under ambient conditions of 10,000 fc and 2,000 fl of luminance. The contrast achievable under ambient conditions of 10,000 fc illumination, viewed directly on the center line varied from 3.0 to 50.0, though most selections were around a contrast of 10.0. The same results were found for a narrow field viewing angle (± 15° off center viewing field), viewed directly on the center line. For the ambient conditions of 10,000 fc a contrast between 3.0 and 5.0 was most selected as adequate for visual performance; a contrast of 3.0 and 4.0 were selected for 8,000 fc and 500 fl ambient conditions; a contrast 3.0 through 5.0 was selected for 2,000 fc and 2,000 fl ambient conditions; and a contrast of 3.0 and 4.0 were most selected for the ambient conditions of 10,000 fc and 3,000 fl. When asked for a recommendation based on cost and performance, a contrast of 4.0 was given most under all ambient conditions presented. Most felt these contrast levels would be achievable by industry in 3 years. No agreement could be made on how contrast is related to cost (linear, square law, or exponential), but most thought reliability degradation was not affected by an increase in contrast.

Many general comments were made about contrast. It was apparent that contrast was inter-related to many factors, such as viewing angle, reflectance, and luminance. It will be very difficult to obtain a general answer for contrast without specifying values for these other factors. Many also noted that contrast is a characteristic of the backlight, not of the AMLCD.

5.5 Luminance

The most selected maximum luminance level currently achievable in AMLCD technology was 176-225 ft Lamberts. This level was also said to provide adequate visual performance in even the most extreme ambient conditions. Many respondents indicated there was a low correlation between luminance and cost; however, others selected exponential and square law relationships. One of the exponential graphs showed a sharp increase beginning between the luminance levels

of 200 and 250 Ft L. When asked for a recommendation based on cost and performance, most selected a luminance of 200 Ft L. With a single backlight system, most said the achievable ratio of full luminance to off was 2,000:1. Most said that a 30% luminance degradation in 10,000 hours was achievable with current backlighting technology.

A ± 10% luminance variation was thought to be achievable across the usable area of display and a ± 2.5% luminance variation was thought achievable within a 0.5 inch diameter. With respect to human ability to detect luminance levels, responses varied from 10 to 25 percent across the entire screen and from 2.5 to 10 percent within a 0.5 inch circular area as acceptable luminance variation percentages. Many respondents indicated current technology could provide luminance variation levels needed to meet human perception requirements, however, others stated this technology would not be available for 2 years. A cost versus luminance variation curve varied in description between no correlation, linear, square law, and exponential. When asked for recommendations of luminance variation levels based on cost and performance, 15 to 30 percent was selected across the entire screen and 2 to 2.5 percent was selected within a 0.5 inch circular area.

5.6 Gray Shades

Most respondents selected 64 as the maximum number of gray levels possible, given current technology and materials for AMLCDs. Based upon human perception, most felt only 8 to 16 gray levels were discernible for alphanumeric and graphic data while 32 to 128 were discernible for color video and monochrome video data. These values were also selected most often when considering cost and performance. Most respondents thought technology should meet these limits of human perception within the next few years. Many stated gray shades were linearly related to cost, some responses indicated an exponential relationship. Of the exponential responses, one graph showed a dramatic up-swing after 64 gray levels. No agreement was found as to how reliability degradation was affected by gray levels; the answers varied from linear to exponential to square law, to little or no correlation. Nearly all respondents thought it was possible to match the gray shade luminance levels to the Munsell value scale rather than space the levels linearly.

5.7 Chromaticity

Based upon units on the 1976 CIE UCS, most chose < 0.015 or < 0.025 unit as the chromaticity deviation achievable for any 0.5 inch diameter circular area on the surface of a given display module. When asked the chromaticity deviation limit achievable between any given display module and selected standard chromaticity, most selected < 0.035 based on units on the 1976 CIE UCS. For the three primary colors, red, green, and blue, the maximum discernible chromaticity deviation was 0.02 to 0.03, 0.02 to 0.03, and 0.03 to 0.035 unit, respectively. Most found chromaticity deviation exponentially related to cost and chose 0.3 unit as the best chromaticity deviation for all primary colors based on cost and performance. Table 5-1 provides the relative maximum intensities achievable for the primary colors, with green as 100%.

Table 5-1. Relative Red, Green, Blue Intensities

Percent Intensity		
Red	Green	Blue
80	100	60
68	100	78
64	100	32
50	100	35
45	100	15
42	100	25

5.8 NVIS

Most respondents indicated the radiance maximums specified for Types I and II NVIS in MIL-L-85762 could be met for Class B, however, some stated Class A could not be met. These maximums could be met by using a separate NVIS backlight and/or using additional filters. Most felt there would be a 15 to 20 percent increase in cost to achieve Class A NVIS compatibility and a 10 to 20 percent increase for Class B compatibility. If NVIS hardware was to be added-on instead of built-in some indicated it could take from 1 to 30 minutes to modify the display for an NVIS mission and many stated the display would have to be removed from the aircraft for NVIS preparation.

5.9 Time Based Effects

Most respondents felt that 60 Hz was the maximum achievable update rate for current AMCLD technology, but thought this rate could increase in the next 5 years to rates of 60 Hz through 120 Hz. There was no agreement on what function update rate would play in cost (linear, square law, exponential, or none); however, many saw the relationship between reliability degradation and update rate as being linear. Ten milliseconds was the most commonly selected minimum achievable response time of individual pixels in AMLCDs at 25°C, which would result in a 60 Hz refresh rate. This refresh rate should be sufficient to remove the perception of flicker in the AMLCD displays in a dynamic aircraft environment. Most selected 20 milliseconds as the best response time based on cost and performance. The majority of responses stated the minimum reflectance achievable off of all combined surfaces of the active display area of an AMLCD module ranged from 0.5 to 1.5 percent. Little to no reduction in minimum reflectance was anticipated over the next 5 years.

5.10 Display Defects

The minimum percentage of subpixel defects that can be reasonably attained in a production run with AMLCD processes and materials is currently 0.005 to 0.010 percent according to most respondents; this could decrease to values ranging from 0.001 to 0.005 percent in the next 5 years. Because subpixel defects is a matter of volume and process, most thought that cost versus subpixel defect percentage was an exponential relationship. The two most selected answers for current highest attainable ratio of display area (in^2) to cluster defects with AMLCDs were 36:1 and 64:1. The most commonly given minimum operating temperatures for AMLCDs were -55°C and -10°C and +75°C was given most as the maximum operating temperature. Most expressed a 5-minute warm-up time from -55°C to achieve full specification performance. Many respondents indicated the displays should not be stored at temperatures lower than -55°C and higher than 90 to 100°C.

5.11 Display Size

Most respondents indicated that AMLCD displays would weigh approximately 0.05 lb per square inch, but some felt they may weigh as much as 0.20 lb per square inch. The maximum viewing area achievable with current technology was thought to be between 64 and 144 square inches. The viewing area to cost relationship was most commonly expressed as a square law relationship; however, one respondent presented a stairstep graph with a dip at 48 in^2 due to the availability of laptop personal computer displays. Reliability degradation was thought to be linear with respect to viewing area.

5.12 Mean Time Between Failure

Question 86 of the survey broke down the displays into types in order to get resolutions, viewing angles, gray levels, and mean time between failures (MTBF). Type I is a 4x4 inch display with low resolution, a narrow viewing angle and 8 gray levels. Most respondents thought an 80 pixel per inch resolution and a 30 to 60 degree viewing angle would be sufficient. They also predicted a 10,000 hours for MTBF. Type II is a 6x6 inch display with moderate resolution, a moderate viewing angle and 32 gray levels. Most respondents thought an 80 pixel per inch resolution and a 30 to 90 degree viewing angle would be sufficient. They also predicted 5,000 to 10,000 hours for MTBF. Type III is an 8x8 inch display with high resolution, a high viewing angle and 128 gray levels. Most respondents thought an 80 pixel per inch resolution and a 40 to 120 degree viewing angle would be sufficient. They also predicted 2,500 to 10,000 hours for MTBF.

5.13 Cost/Reliability Analysis

The survey results indicated that the top five cost drivers were, in order, size, resolution, display defects, viewing angle and luminance. The top five reliability degradation factors were, in order, resolution, luminance, size, gray shades, and time based effects. Most respondents felt that AMLCDs could meet vibration levels encountered in jet, prop, and rotor aircraft.

APPENDIX A

1.0 AMLCD INDUSTRY SURVEY COMPANY DISTRIBUTION LIST

Active Matrix Consulting *
Advanced Technology Incubator, Inc.
Aerospace Display Systems
Allied-Signal Aerospace (NJ) *
Allied-Signal Aerospace Co. (Ohio)
American Telephone and Telegraph *
Astronautics Corporation of America
Avionics Display Corporation
B.F. Goodrich Aerospace
Battelle
Burnette Engineering
Chrysler Motors Corporation
Corning Advanced Display Products
Cybernet Systems Corporation
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Dimension Technologies Inc.
Display & Technologies Inc.
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Electronic Design Inc.
GEC Marconi Avionics Inc. *
General Research
General Motors Corporation
Godfrey Engineering
Grimes Aerospace Co.
Harris Corporation
Hewlett-Packard Co.
Honeywell
Honeywell Defense Avionics System (NM) *
Honeywell Systems & Research Ctr. (AZ) *
Hughes Aircraft Company
Image Quest
In-Focus Systems
International Business Machines
Interstate Electronics Corp. (Ohio)
Interstate Electronics Corp. (CA)
JWK, Inc.
Kaiser Electronics
Litton Systems Canada Limited *
Lockheed Aeronautical Systems Co. (GA)
Lockheed Ft-Worth Co. (TX)
Lockheed Sanders (NH) *
Magnascreen Corp.
McDonnell Aircraft (St. Louis, MO) *
McDonnell Douglas Aerospace (CA)
McDonnell Aircraft Co. (St. Charles, MO)
Norden Systems
Northrop
Optical Imaging Systems, Inc.
Rockwell International Corp. *
SAI Technology Division *
SAIC Computer Systems Div.
SCI
Smiths Industries *
Standish Industries *
Syntronics
Tektronix Avionics
Teledyne Systems Co. *
Xerox PARC

*** Responded to survey**
4 Anonymous respondents

APPENDIX B

AMLCD INDUSTRY SURVEY QUESTIONNAIRE

September 30, 1993

RESOLUTION

1. What is the maximum resolution state-of-the-art color Active Matrix Liquid Crystal Display (AMLCD) technology has achieved?

4 a. 80 pixels per inch
1 b. 100 pixels per inch
6 c. 120 pixels per inch
3 d. 140 pixels per inch
2 e. Other, please specify: **169, 180**

2. What is the maximum resolution state-of-the-art monochrome AMLCD technology has achieved?

1 a. 80 pixels per inch
1 b. 100 pixels per inch
0 c. 120 pixels per inch
1 d. 140 pixels per inch
12 e. Other, please specify: **145, 160 (80 Quad), 164, 200, >210, 230, 256, 280, 284, 300, 500, 508**

3. For the display data listed below, what value of resolution do you feel will allow the display to provide performance at the limits of human perception?

a. Alphanumeric Data ___ pixels per inch **(2) 50, 76, (3) 80, < 100, (3) 100, 120, 125, 150, 169, 200, 300**
b. Graphic Data ____ pixels per inch **80, (6) 100, 120, 125, (2) 150, 169, 200, 200+, 250, 300**
c. Color Video Data ____ pixels per inch **82, (3) 100, (2) 120, 125, 128, 140, (2) 150, 169, (2) 200, 250, (2) 300**
d. Monochrome Video Data ____ pixels per inch **(2) 100, 120, 128, (2) 140, (2) 150, 160 min, 164, 200, (2) 250, (2) 300, 318**

4. If current resolution capabilities are not capable of providing adequate visual performance, when do you believe the resolution capability will meet or exceed the requirement?

0 a. 1 year
1 b. 2 years
3 c. 3 years
4 d. 5 years
0 e. > 5 years
5 currently can meet

5. What function best describes the cost versus resolution curve for AMLCD? (Please provide a sketch if possible)

Sketch of Curve

1 a. Linear

4 b. Square Law

7 c. Exponential

1 d. Other, please specify: **polynomial**

6. What function best describes the reliability degradation versus resolution curve for AMLCDs? (Please provide a sketch if possible)

Sketch of Curve

4 a. Linear

5 b. Exponential

5 c. Other, please specify: **square root, square law, there should be no degradation**

7. What value of resolution would you recommend for the following types of display data based on cost and display performance criteria?

a. Alphanumeric Data ___ pixels per inch **(2) 50, (2) 60, 76, (4) 80, (3) 100, 125, 160 min, 200**
b. Graphic Data ___ pixels per inch **76, (5) 80, 80 min, (4) 100, 150, 160 min, (2) 200**
c. Color Video Data ___ pixels per inch **76, (3) 80, 80 min, 82, (3) 100, 120, 140, (2) 150, 160 min, 200**
d. Monochrome Video Data ___ pixels per inch **76, (2) 120, (3) 140, (2) 150, (3) 160 min, 164, 180, 200**

PIXEL CONFIGURATION

8. What color pixel configuration is predominant in the current AMLCD market?

8 a. Stripe (RGB)
2 b. Triad (RGB)
3 c. Square (4 subpixels, 2 green) (RGBG)
0 d. Other, please specify: _____

9. Please list the relative advantages and disadvantages of the pixel configurations below. For instance, the triad configuration may be capable of higher resolutions while the stripe configuration may be the least costly.

	Advantages	Disadvantages
a. Stripe		
b. Triad	**See Table 4-1**	
c. Square		
d. Other		

10. For the following display types, please specify the color pixel configuration you would recommend based on cost and performance criteria.

a. Alphanumeric Display **(8) Stripe, (7) Square**
b. Graphics Display **(5) Stripe, (7) Square, (3) Triad, Frame Sequential**
c. Video Display **(3) Stripe, (3) Square, (7) Triad, (2) Triad/Quad**
d. Multifunction Display **(4) Stripe, (7) Square, (3) Triad, (2) Quad** (both color & monochrome)

VIEWING ANGLE

11. What is the widest horizontal viewing angle achievable by AMLCD technology under the brightest (worst case) lighting conditions encountered in airborne cockpits?

2 a. ± 20 degrees off center
6 b. ± 40 degrees off center
3 c. ± 60 degrees off center
4 d. ± 80 degrees off center
1 e. Other, please specify: **± 30**

12. Assuming the conditions and horizontal viewing angle selected in Question 11, what is the vertical viewing angle that can be achieved?

a. Vertical viewing angle ____ in degrees **10, 20, (2) 25, (4) 30, (3) 45, 55, (2) 60, +25/-10**, +10/-30

13. What function best describes the cost versus viewing angle curve for AMLCDs? (Please provide a sketch is possible)

Sketch of Curve

4 a. Linear
1 b. Square Law
3 c. Exponential
4 d. Other, please specify: **polynomial, (3) no dependence**

14. What function best describes the reliability degradation versus the viewing angle curve for AMLCDs? (Please provide a sketch if possible)

		Sketch of Curve
1	a. Linear	
1	b. Exponential	
8	c. Other, please specify: little or no effect	

15. Is it possible to offset the viewing angle from the center of the screen?

	Yes	No
a. In the horizontal plane	14	2
b. In the vertical plane	14	2
c. In both planes at once	11	2

16. Can the viewing angle offset be adjusted in the cockpit or must it be set at a maintenance facility or set at the time of manufacture?

5	a. Cockpit adjustable
4	b. Maintenance action
6	c. Manufacturer

CONTRAST

17. What contrast is achievable under the ambient conditions of 10,000 fc illumination (assumed over the full viewing angle identified in question 11)?

2	a. 2.0
3	b. 3.0
4	c. 4.0
3	d. 5.0
2	e. Other, please specify: 7.0, 8.0

18. What contrast is achievable under the ambient conditions of 8,000 fc and 500 fl of luminance (assumed over the full viewing angle identified in question 11)?

0 a. 2.0
3 b. 3.0
4 c. 4.0
5 d. 5.0
2 e. Other, please specify: 8.0, 6.0

19. What contrast is achievable under the ambient condition of 2,000 fc and 2,000 fl of luminance (assumed over the full viewing angle identified in question 11)?

2 a. 2.0
1 b. 3.0
2 c. 4.0
5 d. 5.0
3 e. Other, please specify: 8.0, 10, 20

20. What contrast is achievable under the ambient condition of 10,000 fc and 2,000 fl of luminance (assumed over the full viewing angle identified in question 11)?

4 a. 2.0
3 b. 3.0
3 c. 4.0
2 d. 5.0
2 e. Other, please specify: 8.0, 10

21. What contrast is achievable under the ambient condition of 10,000 fc illumination with the viewing angle identified in Question 11 and viewed directly on the centerline?

0 a. 2.0
1 b. 3.0
1 c. 4.0
4 d. 5.0
9 e. Other, please specify: > 5.0, 5.66, 6.0, 8.0, (3) > 10.0, 15.0, 20-50

22. What contrast is achievable under the ambient condition of 10,000 fc illumination with a narrow field of viewing angle (assume ± 15° off center viewing field) and viewed directly on the centerline?

0 a. 2.0
0 b. 3.0
2 c. 4.0
3 d. 5.0
7 e. Other, please specify: **5.66, 8.0, 10.0, (2) > 10.0, 15.0, 50**

23. What contrast do you feel is adequate for visual performance under the ambient conditions listed below?

a. 10,000 fc	**2.0, (3) 3.0, (2) 4.0, (3) 5.0, 6.0, (2) 8.0**
b. 8,000 fc, 500 fl	**2.0, (2) 3.0, (3) 4.0, (2) 5.0, (2) 8.0, 10.0, 12.0**
c. 2,000 fc, 2,000 fl	**2.0, (3) 3.0, (2) 4.0, (3) 5.0, 8.0, 10.0, 25.0**
d. 10,000 fc, 3,000 fl	**(3) 3.0, (2) 4.0, 4.66, (3) 5.0, 8.0, 20.0**

24. If adequate contrast levels are not currently achievable, when do you believe the contrast capability will be met?

1 a. 1 year
0 b. 2 years
7 c. 3 years
1 d. 5 years
0 e. > 5 years
2 currently can meet

25. What function best describes the cost versus contrast curve for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

3 a. Linear
2 b. Square Law
3 c. Exponential
2 d. Other, please specify: **dog leg, square root**

26. What function best describes the reliability degradation versus contrast curve for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

2 a. Linear

3 b. Exponential

5 c. Other, please specify: square law, (4) no dependencies

27. What value of contrast would you recommend for the following ambient conditions based on cost and performance criteria?

a. 10,000 fc	2.0, 3.0, (3) 4.0, (2) 5.0, 6.0, 7.0, (2) 8.0, 5.0-20.0
b. 8,000 fc, 500 fl	3.0, (4) 4.0, (2) 5.0, (2) 8.0, 10.0, 12.0, 5.0-20.0
c. 2,000 fc, 2,000 fl	(2) 3.0, (4) 4.0, (2) 5.0, 8.0, 5.0-20.0, 10.0, 50.0
d. 10,000 fc, 2,000 fl	3.0, (4) 4.0, 4.66, (2) 5.0, 8.0, (2) 5.0-20.0

LUMINANCE

28. What is the maximum luminance levels achievable with current AMLCD technology?

3 a. 125-175 ft Lamberts
4 b. 175-225 ft Lamberts
2 c. 225-275 ft Lamberts
3 d. 275-325 ft Lamberts
1 d. Other, please specify: > 400

29. Based on the following conditions:

1. maximum sunlight incident directly in the pilot's eyes, and
2. display located in shade on the cockpit panel

What luminance level is required to provide adequate visual performance:

2 a. 125-175 ft Lamberts
8 b. 176-225 ft Lamberts
1 c. 226-275 ft Lamberts
2 d. 276-325 ft Lamberts
2 e. Other, please specify: _____

30. If current luminance levels are not capable of providing adequate visual performance, when do you believe the luminance level will meet or exceed the requirement?

1 a. 1 year
1 b. 2 years
1 c. 3 years
1 d. 5 years
1 e. > 5 years
4 currently can meet

31. What function best describes the cost versus luminance level for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

3 a. Linear

3 b. Square Law

3 c. Exponential

5 d. Other, please specify: **(3) low correlation, polynomial, dog leg**

32. What function best describes the reliability degradation versus luminance curve for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

3 a. Linear

7 b. Exponential

2 c. Other, please specify: **(2) square law**

33. What luminance levels would you recommend for the conditions stated in Question 29 based on cost and performance criteria? **150, 160, 170, 175, (4) 200 225, 250, 280, 500**

34. What ratio of full luminance to off is achievable with a single backlight system?

2 a. 250:1
2 b. 500:1
0 c. 750:1
1 d. 1000:1
10 e. Other, please specify: **(7) 2,000:1, 3,000:1, 4,000:1, 100:1**

35. What luminance degradation is achievable with current backlighting technology?

1 a. 5% in 10,000 hours
2 b. 10% in 10,000 hours
2 c. 20% in 10,000 hours
7 d. 30% in 10,000 hours
2 e. Other, please specify: 5% in 1,000 hours, 100% in 3,000 hours

36. What luminance variation (of like symbols or areas) is achievable across the usable area of the display?

2 a. ± 5%
5 b. ± 10%
4 c. ± 20%
4 d. ± 30%
2 e. Other, please specify: ±15%, ± 40%

37. What luminance variation within a 0.5 inch diameter circle is achievable?

11 a. ± 2.5%
3 b. ± 5.0%
0 c. ± 7.5%
3 d. ± 10.0%
0 e. Other, please specify: _____

38. For the two conditions stated in Questions 36 and 37, what percentage of luminance variation do you feel is at the limits of human perception with respect to detecting differences in luminance levels?

a. Across entire screen .5, (2) 5, (2) 10 (2) 15, (3) 20, (2) 25, 15 to 30, 30, 40, 50
b. Within 0.5 inch circular area .5, 1, 2, (5) 2.5, 3.5, (2) 5, ± 5, 10, (2) 15, 20

39. If current luminance variation levels are not capable of meeting the levels stated in Question 38, when do you believe the luminance variation levels will meet or exceed the requirement?

0 a. 1 year
3 b. 2 years
1 c. 3 years
1 d. 5 years
0 e. > 5 years

3 currently can meet

40. What function best describes the cost versus luminance variation curve for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

3 a. Linear

4 b. Square Law

2 c. Exponential

2 d. Other, please specify: **(2) low correlation**

41. What luminance variation levels would you recommend for the conditions below based on cost and performance criteria?

a. Access entire screen **1, (2) 5, 10, (2) 15, (3) 20, ± 20, (2) 30, 40, 50**
b. Within 0.5 inch circular area **.2, 1, (2) 2, (3) 2.5, (2) 2-3, (3) 5, 10, 15, 20**

GRAY SHADES

42. What is the maximum number of gray shade levels possible given current technology and materials used in the AMLCD field?

1 a. 16 levels
3 b. 32 levels
7 c. 64 levels
1 d. 128 levels
3 e. Other, please specify: **8 levels over entire viewing angle, (2) 256**

43. What do you think is the maximum number of discernible (based on human perception) gray shade levels for AMLCD technology for these data display types?

a. Alphanumeric Data **(2) 4, (5) 8, (5) 16, 32, 64, 300**
b. Graphic Data **2-6, (3) 8, 8-16, (4) 16, 32, (2) 64, (2) 128, 300**
c. Color Video Data **14, 16, (3) 32, (4) 64, (3) 128, 256, 300**
d. Monochrome Video Data **8, 14, (2) 16, (2) 32, (4) 64, (2) 128, 128-256, 256, 300**

44. If the current gray shade level capability is below the number of discernible levels based on human perception, when do you believe the level of gray shading will meet or exceed the requirement?

2 a. 1 year
4 b. 2 years
2 c. 3 years
0 d. 5 years
2 e. > 5 years

45. What function best describes the cost versus gray shade level curve for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

5 a. Linear
1 b. Square Law
5 c. Exponential
3 d. Other, please specify: **no dependence, polynomial, dog leg**

46. What function best describes the reliability degradation versus gray shade curve for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

4 a. Linear
3 b. Exponential
5 c. Other, please specify: **(2) square law, (2) no correlation, slight variation**

47. For the following display types, please specify the number of gray shades you would recommend based on cost and performance criteria?

a. Alphanumeric Data **(3) 2, (3) 4, (7) 8, 64**
b. Graphic Data **2, (2) 4, (3) 8, (5) 16, (2) 64, 128**
c. Color Video Data **16, 16+, (3) 32, (6) 64, (3) 128**
d. Monochrome Video Data **16+, (3) 32, (5) 64, (4) 128, 256**

48. Is it possible to match the gray shade luminance levels to the Munsell value scale rather than space the levels linearly?

Yes 11 No 1

CHROMATICITY

49. What chromaticity deviation limits are achievable for any 0.5 inch diameter circular area on the surface of a given display module based on units on the 1976 CIE UCS?

5 a. < 0.015 units
7 b. < 0.025 units
2 c. < 0.035 units
1 d. Other, please specify: 0.05

50. What is the chromaticity deviation limit achievable between any given display module and a selected standard chromaticity based on units on the 1976 CIE UCS?

1 a. < 0.015 units
3 b. < 0.025 units
9 c. < 0.035 units
1 d. Other, please specify: much > 0.035

51. What do you think the maximum chromaticity deviation (based on units of the 1976 CIE UCS) is before a discernible color difference occurs for the three primary colors:

a. Red (3) 0.015, (4) 0.02, (2) 0.025, (3) 0.03, 0.04
b. Green (2) 0.01, (2) 0.015, (2) 0.02, (3) 0.025, (3) 0.03, 0.035
c. Blue 0.01, 0.015, 0.02, 0.025, (6) 0.03, (2) 0.035, 0.05

52. If the current chromaticity deviations are greater than levels identified in Question 51, when do you believe the deviation levels will meet or exceed the requirement?

0 a. 1 year
0 b. 2 years
3 c. 3 years
1 d. 5 years
1 e. > 5 years
5 **can currently meet**

53. What function best describes the cost versus chromaticity deviation curve for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

2 a. Linear

0 b. Square Law

4 c. Exponential

3 d. Other, please specify: **(3) no correlation**

54. For the following primary colors, please specify the chromaticity deviation you would recommend based on cost and performance criteria?

a. Red **0.01, 0.015, 0.02, (5) 0.03, 0.035, 0.04, 0.05, 0.3**
b. Green **0.01, 0.015, 0.02, (5) 0.03, (2) 0.035, (2) 0.05, 0.3**
c. Blue **0.01, 0.015, 0.02, 0.025, (5) 0.03, (2) 0.05**

55. For the following primary colors, please specify the largest difference in percent of maximum intensities. For instance, if green will yield the maximum intensity, what percentage below this intensity is red and blue. Please indicate the color with the maximum intensity.

a. Red _____
b. Green _____
c. Blue _____

Red	Green	Blue		
80	100	60		
70	100	82		
68	100	78		
42	100	25		
45	100	15		
50	100	35		
64	100	32		
middle	100	low		
25	65	10	=	100
30	60	10	=	100
30	58	11	=	100

NVIS

56. *Can you meet the NVIS radiance maximums specified for Types I and II, Class A or Class B in MIL-L-85762 for color AMLCDs?*

	Yes	No
a. Class A	**8**	**5**
b. Class B	**12**	**1**

57. If you cannot meet current NVIS requirements, when do you think you will be able to?

1 a. 1 year
0 b. 2 years
0 c. 3 years
0 d. 5 years
0 e. > 5 years

58. How would the NVIS radiance maximums specified for Types I and II, Class A or Class B in MIL-L-85762 be met?

2 a. Separate NVIS backlight
2 b. Additional filters
5 c. Both a) and b)
1 d. Other, please specify: **Not in MIL-SPEC applications**

59. For a given display, how costly (in terms of % increase) would it be to achieve NVIS compatibility?

a. Class A **2, 10, 13, (4) 15, (2) 20, not achievable**
b. Class B **small, 2, (5) 10, 15, (2) 20**

60. If the NVIS hardware is add-on instead of built-in, how long will it take (in minutes) to modify the display for a NVIS mission?

a. Class A **(2) 1, 20, 30 min**
b. Class B **(2) 1, 20, 30 min**
4 c. Not possible to meet full NVIS and daylight capability with add-on hardware

61. Will converting a display to become NVIS compatible require removal of the display from the aircraft?

Yes **9** No **4**

TIME BASED EFFECTS

62. What is the maximum achievable update rate for current AMLCD technology and materials?

0 a. 15 Hz
2 b. 30 Hz
0 c. 45 Hz
10 d. 60 Hz
3 e. Other, please specify: **80, 100, 120**

63. What do you believe will be the maximum achievable update rate for AMLCD technology and materials in 5 years?

0 a. 45 Hz
3 b. 60 Hz
2 c. 75 Hz
3 d. 90 Hz
4 e. Other, please specify: **100, 120, (2) 180**

64. What function best describes the cost versus update rate for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

3 a. Linear
2 b. Square Law
2 c. Exponential
4 d. Other, please specify: **stair case, polynomial, slight dependence, no correlation**

65. What function best describes the reliability degradation versus update rate for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

4 a. Linear
1 b. Exponential
5 c. Other, please specify: **square law, stair case, (2) slight dependence, none**

66. What is the minimum achievable response times (rise & fall times) of individual pixels in AMLCDs at 25°C?

1 a. 2 milliseconds
1 b. 5 milliseconds
4 c. 10 milliseconds
3 d. 20 milliseconds
7 e. Other, please specify: **(2) 15, (4) 30, 66**

67. What is the maximum refresh rate that can be achieved using the pixel response time of Question 66?

8 a. 60 Hz
3 b. 90 Hz
3 c. 120 Hz
0 d. 150 Hz
1 e. Other, please specify: **80 Hz**

68. What refresh rate do you feel is adequate to remove the perception of flicker in AMLCD displays in the dynamic aircraft environment?

9 a. 60 Hz
3 b. 90 Hz
1 c. 120 Hz
0 d. 150 Hz
1 e. Other, please specify: **30**

69. If adequate refresh rates are not currently achievable, when do you believe the refresh rates will be met?

0 a. 1 year
0 b. 2 years
2 c. 3 years
1 d. 5 years
0 e. > 5 years **3 can currently achieve**

70. What function best describes the cost versus response times for individual pixels in an AMLCD? (Please provide a sketch, if possible)

Sketch of Curve

2 a. Linear
1 b. Square Law
5 c. Exponential
3 d. Other, please specify: **(2) slight dependence, no correlations**

71. What response times would you recommend based on cost and performance criteria?
10, 15, < 20, (7) 20, 30, 33, 35, 75 msec.

72. What is the minimum reflectance achievable off of all the combined surfaces of the active display area of an AMLCD module?

5 a. less than 0.5%
4 b. less than 1.0%
3 c. less than 1.5%
1 d. less than 2.0%
2 e. Other, please specify: (2) 5.0%

73. What do you believe will be the minimum reflectance achievable off of all the combined surfaces of an AMLCD module in 5 years?

1 a. less than 0.2%
2 b. less than 0.3%
6 c. less than 0.5%
3 d. less than 1.0%
2 e. Other, please specify: (2) < 2.0%

DISPLAY DEFECTS

74. What is the minimum percentage of subpixel defects that can be reasonably attained in a production run with current AMLCD processes and materials?

3 a. 0.005%
4 b. 0.010%
2 c. 0.015%
1 d. 0.020%
2 e. Other, please specify: .002, < .005

75. What function best describes the cost versus subpixel defect percentage for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

1 a. Linear
1 b. Square Law
7 c. Exponential
0 d. Other, please specify: _____

76. What is the minimum percentage of subpixel defects that you feel can be obtained with AMLCD processes and materials in 5 years?

3 a. 0.002
2 b. 0.003
2 c. 0.005
1 d. 0.010
2 e. Other, please specify: (2) 0.001

77. What is the highest attainable ratio of display area (in square inches) to cluster defects that can be currently achieved with AMLCDs?

0 a. 16:1
1 b. 25:1
2 c. 36:1
3 d. 64:1
2 e. Other, please specify: (2) 4:1

78. Assuming adequate heater power is available and that thermally induced stresses are the determining factor, what is the minimum warm-up time from -55°C that current AMLCD materials will require to achieve full specification performance?

4 a. 2 minutes
0 b. 3 minutes
0 c. 4 minutes
6 d. 5 minutes
3 e. Other, please specify: (2) 10, 15 min

79. What are the minimum operating temperatures for the materials used in current AMLCDs?

5 a. -55°C
1 b. -40°C
2 c. -25°C
6 d. -10°C
2 e. Other, please specify: (2) 0°C

80. What are the maximum operating temperatures for the materials used in current AMLCDs?

0 a. +125°C
2 b. +100°C
8 c. +75°C
2 d. +50°C
3 e. Other, please specify: (2) 85°C, 93°C

81. What are the minimum and maximum storage temperatures for the materials used in AMLCDs? (Note: The display must survive the temperature range but not operate at this range.)

a. Minimum temperature -64, (2) -60, -62, (9) -55, (2) -40C
b. Maximum temperature (3) 85, (3) 90, 93, (3) 95, (3) 100, (2) 125C

82. What weights, in pounds per square inch of viewing area size, are achievable with current AMLCD materials?

2 a. 0.05 lbs per sq in
1 b. 0.10 lbs per sq in
1 c. 0.15 lbs per sq in
1 d. 0.20 lbs per sq in
1 e. Other, please specify: < 0.05

83. What is the maximum viewing area, in square inches, that is achievable with current AMLCD technology?

4 a. 64 square inches
5 b. 100 square inches
4 c. 144 square inches
1 d. 225 square inches
2 e. Other, please specify: 139, 250

84. What function best describes the cost versus viewing area for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

3 a. Linear

5 b. Square Law

3 c. Exponential

3 d. Other, please specify: (2) polynomial, stair case

85. What function best describes the reliability degradation versus viewing area for AMLCDs? (Please provide a sketch, if possible)

Sketch of Curve

6 a. Linear

3 b. Exponential

1 c. Other, please specify: none

86. What is the maximum mean time between failure (MTBF) that can be achieved with current AMLCD technology for the following display types? (Assume that backlight degradation is not considered a failure.)

Type I
- Size 4x4 (inches)
- Resolution low (indicate pixels per inch) 50, (2) 60, (4) 80, 100, (2) 128
- Viewing angle narrow (indicate angle) 10, 15, 20, 25, (2) 30, (2) 40, (2) 60
- Gray shading 8 levels

0 a. 2,500 hr
0 b. 5,000 hr
2 c. 7,500 hr
6 d. 10,000 hr
2 e. Other, please specify: 15,000 hr, 20,000 hr

Type II -
- Size 6x6 (inches)
- Resolution moderate (indicate pixels per inch) (6) 80, 85, 90, (2) 100
- Viewing angle moderate (indicate angle) 20, (2) 25, (2) 30, (2) 40, 60, (2) 90
- Gray shading 32 levels

0 a. 2,500 hr
5 b. 5,000 hr
1 c. 7,500 hr
3 d. 10,000 hr
1 e. Other, please specify: 20,000 hr

Type III
- Size 8x8 (inches)
- Resolution high (indicate pixels per inch) 64, (3) 80, 100, 120, (2) 151
- Viewing angle high (indicate angle) 20, (2) 40, (2) 45, (2) 60, 120
- Gray shading 128 levels

3 a. 2,500 hr
1 b. 5,000 hr
1 c. 7,500 hr
3 d. 10,000 hr
0 e. Other, please specify: _____

87. Please rank the following characteristics according to their cost impact (top 5 only, number 1 being highest cost driver).

Score			Score		
49	# 2	Resolution	10	# 9	NVIS
27	# 4	Viewing Angle	5	#11	Time Based Effects
12	# 7	Contrast	37	# 3	Display Defects
25	# 5	Luminance	53	# 1	Size
12	# 7	Gray Shades	0	#12	Reliability
6	#10	Chromaticity Deviation	19	# 6	Color/Monochrome

15 responses
highest score = highest driver

88. Please rank the following characteristics according to their reliability impact (top 5 only, number 1 being highest degradation factor).

Score			Score		
45	# 1	Resolution	4	#10	Chromaticity Deviation
1	#12	Viewing Angle	2	#11	NVIS
14	# 7	Contrast	19	# 5	Time Based Effects
44	# 2	Luminance	13	# 6	Display Defects
25	# 4	Gray Shades	33	# 3	Size
8	# 8	Color/Monochrome	5	# 9	Interconnections

89. Will current AMLCDs be able to meet the vibration levels encountered in the following aircraft environments?

	Yes	No
a. Jet Aircraft	15	—
b. Prop Aircraft	12	—
c. Rotor Aircraft	13	1